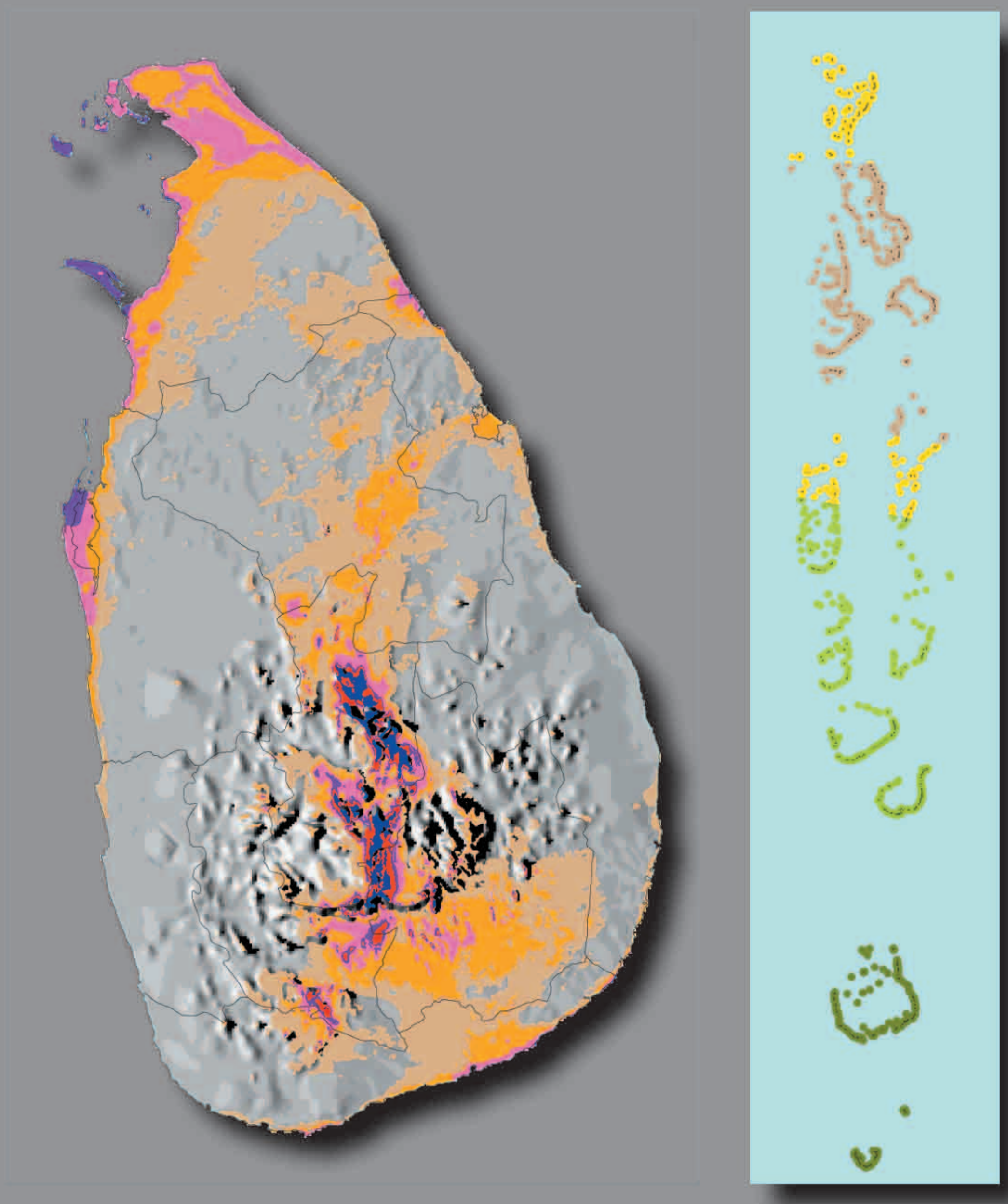
Wind Energy Resource Atlas of Sri Lanka and the Maldives



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Executive Summary

This wind energy resource atlas identifies the wind characteristics and distribution of the wind resource in the countries of Sri Lanka and the Maldives. The detailed wind resource maps and other information contained in the atlas facilitate the identification of prospective areas for use of wind energy technologies for utility-scale power generation, village power, and off-grid wind energy applications. The maps portray the wind resource with high-resolution grids of wind power density at 50-m above ground. The wind maps were created at the National Renewable Energy Laboratory (NREL) using a computerized wind mapping system that uses Geographic Information System (GIS) software.

NREL's sophisticated wind mapping methodology integrates terrain and climatic data sets, GIS technology, and analytical and computational techniques. The meteorological data sources include surface and upper-air data taken from measurement stations, ocean surface winds derived from satellite measurements, and computer model-derived estimates. Mesoscale model data from TrueWind Solutions (an NREL subcontractor) were used for initial estimates of the wind power in Sri Lanka. The initial estimates in certain regions of Sri Lanka were adjusted after NREL's evaluation of the available meteorological data (including measurement data collected by the Ceylon Electricity Board at prospective wind development sites) and other climatic data sets. The primary adjusted regions were selected coastal areas, the central highlands, and areas of northern Sri Lanka. For the Maldives, the most important data was the ocean satellite data, which NREL used in combination with some surface-station data and upper-air data to estimate the wind speed and power. The wind resource at 50 m for the atoll islands in the Maldives is essentially the same as for the surrounding ocean areas, because the individual islands are too small to have a significant effect on the ambient wind resource at 50-m height. Surface roughness data for the Maldives islands were not available, but any trees or buildings will minimally affect the 50-m wind power values on the small islands. However, treed or other areas with obstructions will have considerably reduced resource at 20 m or 30 m compared to the 50 m values.

The wind-mapping results for Sri Lanka show many areas that are estimated to have good-to-excellent wind resources. These areas are concentrated largely in two major regions. The first is the northwestern coastal region from the Kalpitiya Peninsula north to Mannar Island and the Jaffna Peninsula. The second region is the central highlands in the interior of the country, largely in the Central Province but also in parts of Sabaragamuwa and Uva Provinces. Much of the highlands region is over 1500 m in elevation, and the best sites are those that are well exposed to the strong southwest monsoon winds. Other regions with notable areas of good wind resource include the exposed terrain in the southern part of the North Central Province and coastal areas in southeastern part of the Southern Province. High-quality wind measurement data were available to confirm the map estimates of wind resource in specific areas, such as the Kalpitiya Peninsula, the central highlands, and the southeast coast.

The seasonal distribution of the wind resource for a particular site in Sri Lanka depends on elevation, its location, and its exposure to the monsoon flows. Throughout much of Sri Lanka, places exposed to both monsoon flows will have maximum resource from May through September (southwest monsoon) and a secondary maximum resource from December through February (northeast monsoon).

NREL estimates that there are nearly 5000 km^2 of windy areas with good-to-excellent wind resource potential in Sri Lanka. About 4100 km^2 of the total windy area is land and about 700 km^2 is lagoon. The windy land represents about 6% of the total land area (65,600 km^2) of Sri Lanka. Using a conservative assumption of 5 MW per km^2, this windy land could support almost 20,000 MW of potential installed capacity. If the windy lagoons are included, the total wind potential increases to approximately 24,000 MW. If areas with moderate wind resource potential are considered, the estimated total windy land area increases to approximately 10,000 km^2 or almost 15% of the total land area of Sri Lanka. This amount of windy land could support more than 50,000 MW of installed capacity. Additional studies are required to accurately assess the wind electric potential, considering factors such as the existing transmission grid and accessibility.

For the Maldives, the wind map shows the highest resource in the north-central part of the Maldives just north of the capital of Male', from 4.5^o north latitude (N Lat) to 6.5^o N Lat. This region includes North Maalhusmadulu, South Maalhusmadulu, North Miladhunmadulu, South Miladhunmadulu, and Faadippolhu Atolls. The level of resource in these areas is considered good for small-scale village applications and moderate for large applications. North and south of this region the wind resource is slightly lower but still considered good for small-scale and moderate for large-scale wind applications. These areas include the North Thiladhunmathi and South Thiladhunmathi Atolls at the northern end of the Maldives, and North Ari and Male' Atolls near 4^o N Lat. Male', the capital of the Maldives, is included in this wind resource area. The wind resource gradually decreases from Male' southwards with the lowest resource found on the atolls south of 1^o N Lat. However, the wind resource is still considered moderate for small-scale applications and favorable locations for wind energy projects may still be found as far south as Addu Atoll.

The seasonal wind resource distribution varies throughout the north-south extent of the Maldives. In the north-central region, which has the highest annual resource, the seasonal resource is highest from May through October during the west monsoon and from December through January during the northeast monsoon. In the south, the resource is highest from September through November and in May. Throughout much of the Maldives, the lowest resource occurs from February through April.

Although the wind resource maps and other characteristic information provided by NREL will help identify prospective areas for wind energy applications, we strongly recommend that wind measurement programs be conducted to validate the resource estimates and to refine the wind maps and assessment methods.

1.0 Introduction

The United States Agency for International Development (USAID) and the United States Department of Energy (DOE) sponsored a project to help accelerate the widespread use of wind energy technologies in Sri Lanka and the Maldives through the development of a wind energy resource atlas for these countries.

DOE's National Renewable Energy Laboratory (NREL) led the project in collaboration with USAID's South Asia Regional Initiative for Energy Cooperation and Development (SARI/Energy), the Ministry of Power and Energy (Sri Lanka), and the Ministry of Communication, Science, and Technology (Maldives). The primary goals of the project were to develop detailed wind resource maps for all regions of Sri Lanka and the Maldives and to produce a comprehensive wind resource atlas documenting the results.

NREL was responsible for obtaining meteorological data available from U.S. sources, such as the National Climatic Data Center (NCDC) and the National Center for Atmospheric Research (NCAR), that would be useful in the assessment. NREL was also responsible for data analysis, development of the final wind resource maps, and production of the final wind atlas. TrueWind Solutions (an NREL subcontractor) provided mesoscale model data for the initial wind resource estimates in Sri Lanka. Some organizations in Sri Lanka and the Maldives assisted NREL by providing data from in-country sources. The Ceylon Electricity Board (CEB) supplied wind measurement data from 23 sites installed by CEB in different areas of Sri Lanka to assess the wind resource potential and also provided two CEB reports on previous wind resource surveys. In addition to supplying its own data, CEB assisted NREL in identifying and obtaining wind data from other sources in Sri Lanka, such as summaries of historical wind speed data for 14 stations collected by the Department of Meteorology, Sri Lanka. Resource Management Associates (a private company in Sri Lanka) assisted by collaborating with NREL on the data and reviewing the wind resource maps of Sri Lanka. For the Maldives, the National Meteorological Center provided summaries of historical wind speed data for 4 stations.

The "Wind Energy Resource Atlas of Sri Lanka and the Maldives" presents the wind resource analysis and mapping results for these countries. An advanced automated wind mapping technique, developed at NREL with assistance from U.S. consultants, was used to generate the wind resource maps. This technique uses Geographic Information Systems (GIS) to produce high-resolution annual average wind resource maps. In addition to the wind resource maps, the atlas includes information on important wind characteristics, including seasonal and diurnal variability and wind direction frequency.

This atlas is the latest in a series of wind energy resource atlases and assessments produced by NREL. In addition to Sri Lanka and the Maldives, NREL has applied its wind mapping system to produce wind resource assessments of the Dominican Republic (Elliott et al., 2001), the Philippines (Elliott et al., 2001), Mongolia (Elliott et al., 2001) and specific regions of Chile, China, Indonesia, Mexico, and the United States (Schwartz, 1999; Elliott et al., 1999). Many of NREL's international wind resource maps, and some produced by others, can be found on the Web at http://www.rsvp.nrel.gov/wind_resources.html.

The Atlas of Sri Lanka and the Maldives is divided into eight sections. Section 2.0 provides an overview of the geography and climate for both countries. Section 3.0 contains a summary of the fundamentals of wind resource estimation. Section 4.0 describes the wind resource methodology and mapping system. Section 5.0 presents the wind resource data obtained and analyzed for the assessment. Section 6.0 describes the wind resource characteristics and mapping results for Sri Lanka, and Section 7.0 contains an assessment of the wind electric potential in Sri Lanka. Finally, section 8.0 describes the wind resource characteristics and mapping results for the Maldives.

Appendices provide pertinent summaries of wind characteristics data from selected surface meteorological stations, CEB wind monitoring sites, upper-air data, and satellite ocean wind data.

2.0 Geography and Climate of Sri Lanka and the Maldives

2.1 Geography of Sri Lanka

Sri Lanka is an island nation in the Indian Ocean, centered at approximately 81° east longitude and 7° N Lat. just off the southeastern tip of India. Sri Lanka extends approximately 440 km from north to south and 220 km from east to west. The total area of Sri Lanka is approximately 65,610 km^2. Figure 2.1 is a political map of Sri Lanka that shows the major cities and provincial capitals. The population of Sri Lanka is approximately 19.6 million (2002). The capital of Sri Lanka and largest city is Colombo, with a population of approximately 640,000.

The most notable terrain feature in Sri Lanka, as shown in Figures 2.2 and 2.3, is the central highlands located in the south-center of the country. These highlands consist of high plateaus interspersed with several mountain ranges. Mount Pidurutalagala in the central massif at 2,524 meters is the highest point in Sri Lanka. Adams Peak at 2,243 meters and Mount Namunukula at 2,036 meters are located in the southern part of the highlands. A series of escarpments and ledges form the extreme south end of this region. Peaks as high as 1,800 meters are located in the Knuckles Massif located in the north part of the highlands.

Most of the island consists of plains that extend from the coast to the foothills of the central highlands. Ridges and valleys that gradually rise to merge with the central highlands dissect the plain in southwestern Sri Lanka. In the southeast, the plain is relatively level and broken with large hills until it abruptly meets the escarpments of the central highlands. In the east and the north, the plain is flat, and cut by isolated long, narrow ridges that extend from the central highlands. Of note, Mannar Island in the northwest is almost connected to India by a chain of sandbanks and islets.

2.2 Climate of Sri Lanka

Sri Lanka has a tropical climate that includes distinct wet and dry regimes. However, wind regimes in Sri Lanka can also be used to define seasons. The four wind seasons in Sri Lanka are the northeast monsoon (December to February), first inter-monsoon (March and April), southwest monsoon (May to September), and second inter-monsoon (October and November).

The rainfall pattern is complex because of the influences of the monsoon winds and terrain. The south, southwest, and central highlands are considerably wetter than the southeast, north, and north-central regions of the country. The annual precipitation for the major population areas ranges from just over 1000 mm in the northern region to about 2500 mm along the southwest coast. The months of maximum rainfall also vary. For example, along the southwest coast the months of maximum rainfall are April, May, October, and November with the driest months being January and February. In contrast, the northern and northeastern coasts have a precipitation maximum from October through December and a minimum in June and July. The plateau regions of the central highlands have a fairly even distribution of rainfall with a minimum in January and February. The ridges on the southwestern side of the central highlands receive heavy rain during the southwest monsoon, and the ridges on the eastern side of the highlands receive heavy rains during the northeast monsoon. The average temperature in the coastal areas is around

Sri Lanka - Political Base Map

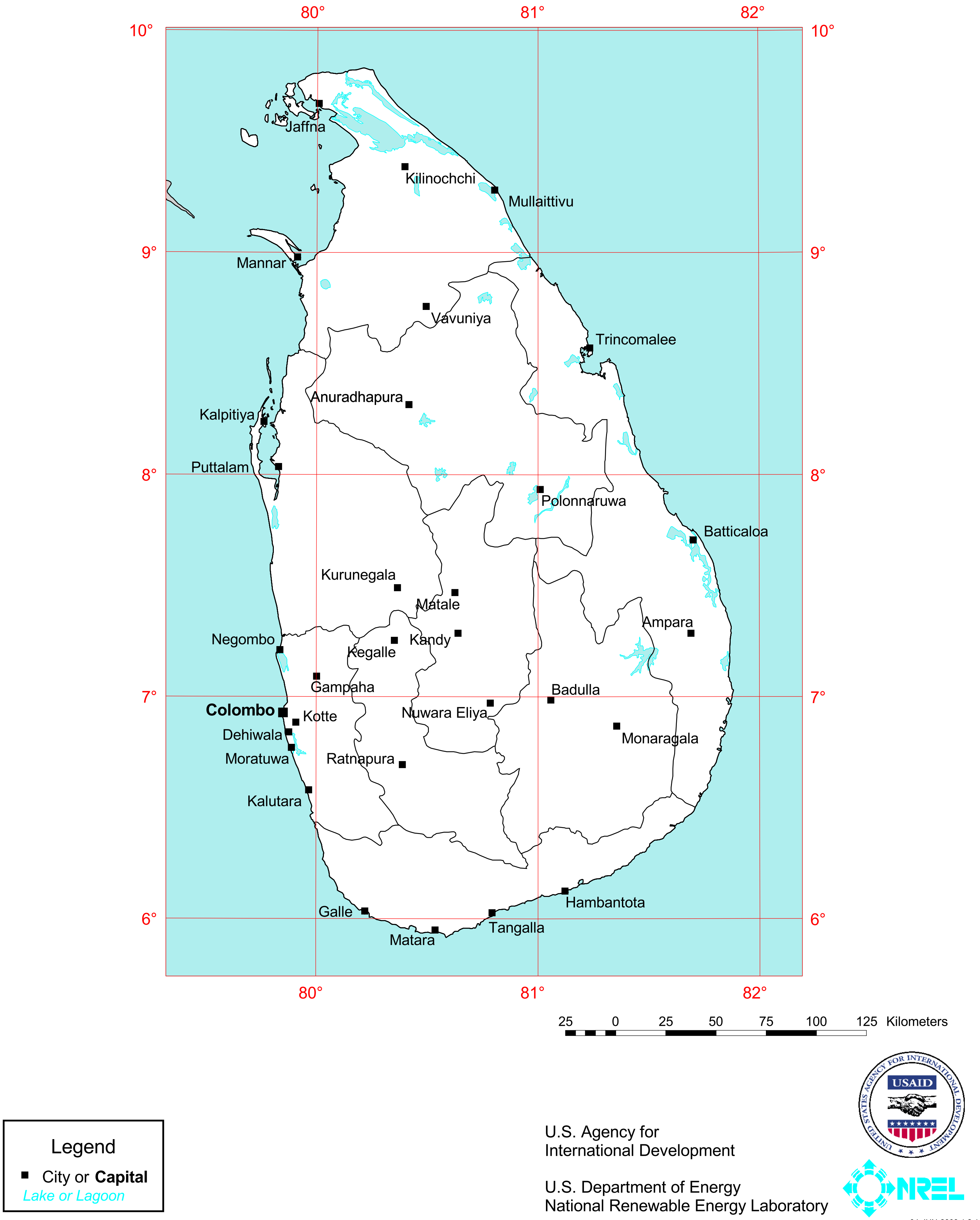

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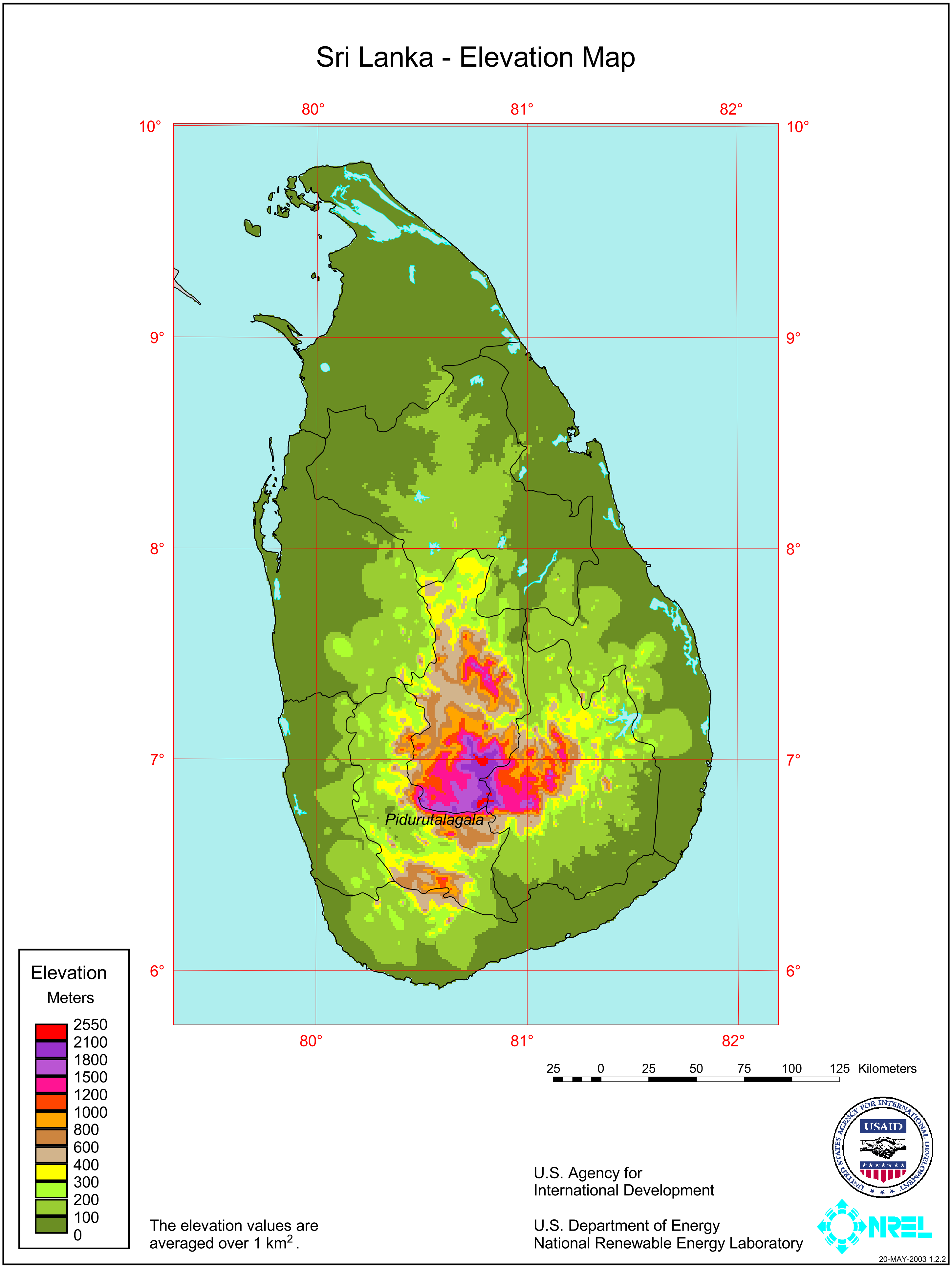
Figure 2-1


Sri Lanka - Elevation Map
80°
81°
82°
10°
9°
8°
7°
6°
Pidurutalagala
Elevation
Meters
2550
2100
1800
1500
1200
1000
800
600
400
300
200
100
0
25 0 25 50 75 100 125 Kilometers
The elevation values are averaged over 1 km^2.
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U.S. Department of Energy National Renewable Energy Laboratory
USAID
NREL
20-MAY-2003 1.2.2

Figure 2-2

Sri Lanka - Hillshaded Relief Map

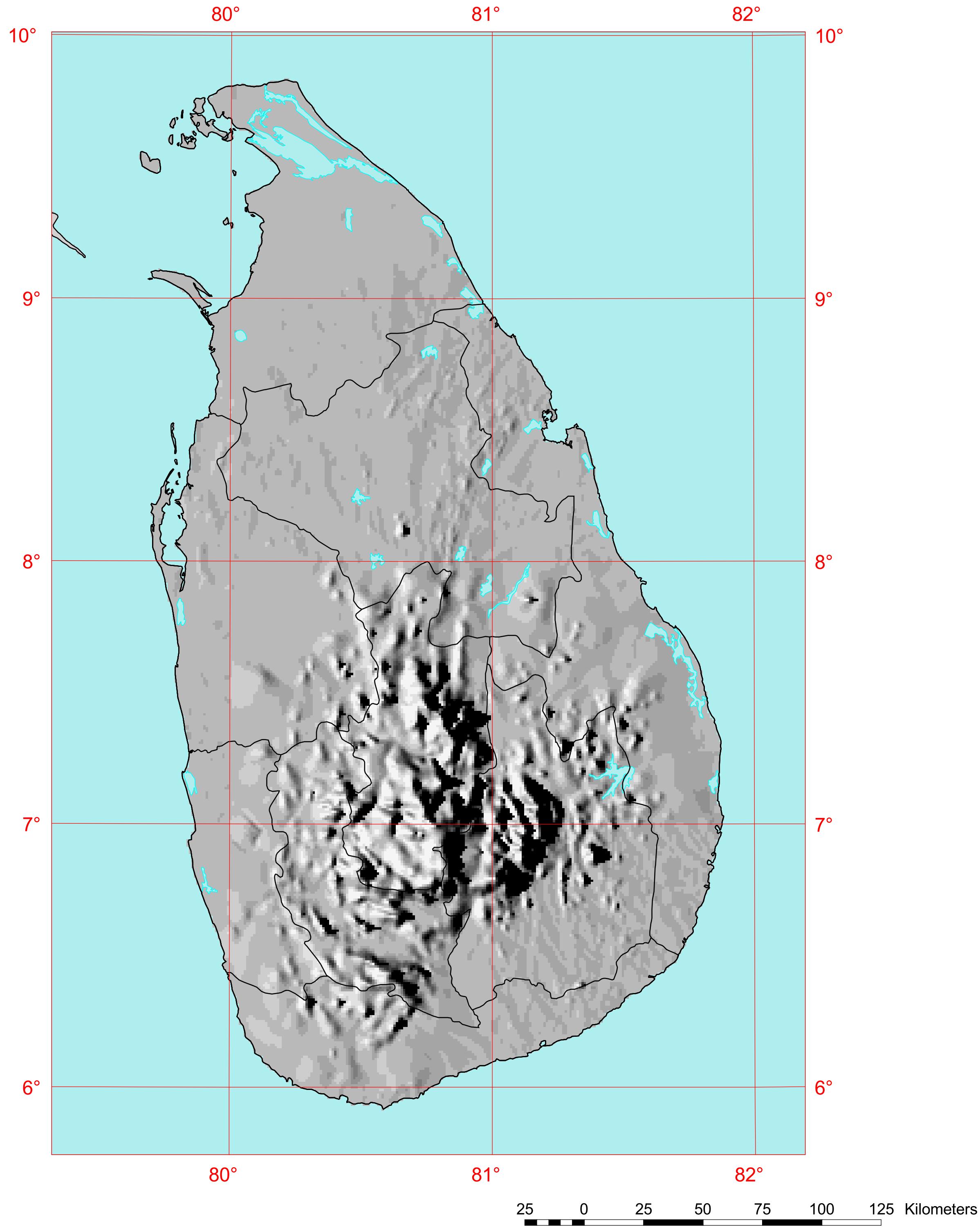

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Figure 2-3

27º to 28º Celsius, while in the higher elevations of the central highlands the average temperatures are considerably cooler, around 15º Celsius.

2.3 Geography of the Maldives

The Maldives is a group of atolls in the Indian Ocean south-southwest of India near the equator. The land area of the Maldives is approximately 300 km^2. It extends approximately 820 km from north to south and 130 km east to west. The northern tip of the Maldives is just north of 7º N Lat. and the southern tip is just south of the equator. The Maldives is centered at approximately 73º East Longitude.

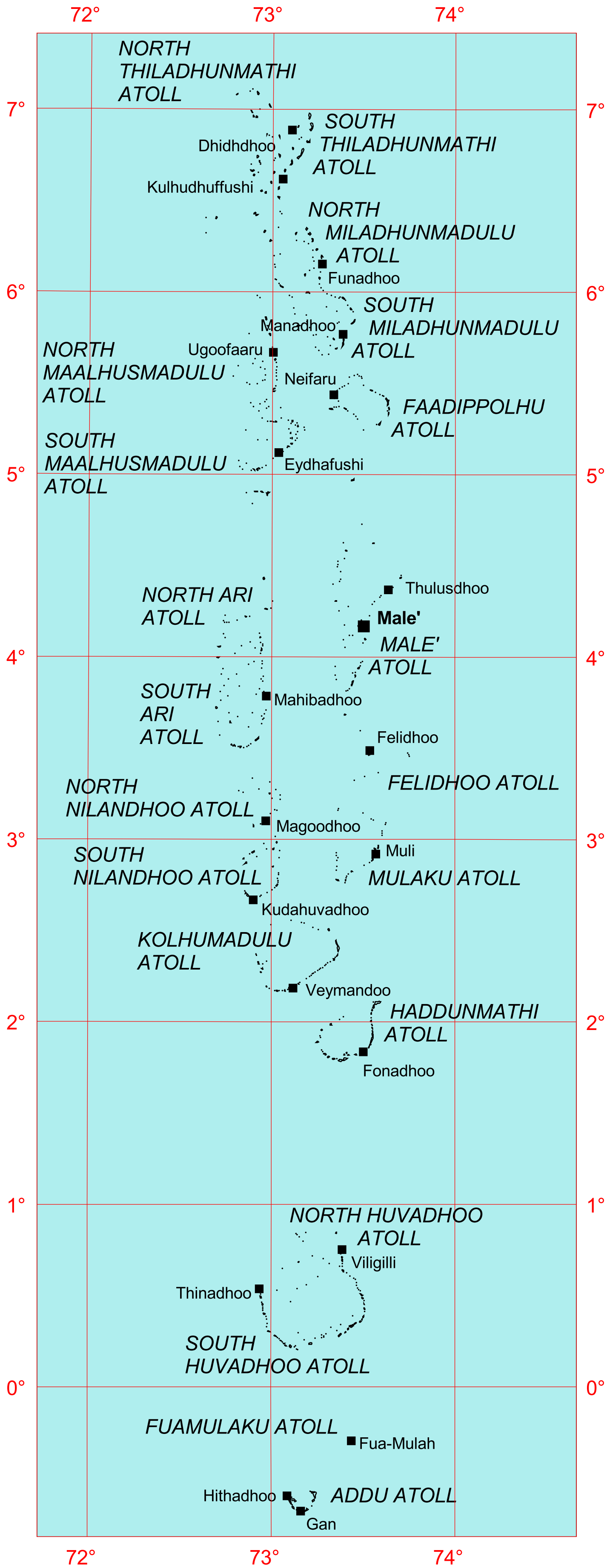
Figure 2.4 is a political map of the Maldives that shows the major cities and the 20 administrative atolls. The population of Maldives is around 320,000 (2002). The capital of the Maldives and largest city is Male', with a population of approximately 81,000.

There are 1,190 islands grouped in clusters of 26 atolls. Most atolls consist of a large, ring-shaped coral reef supporting numerous islands. The islands are composed of live coral reefs and sand bars. The islands average 1 to 2 km^2 in area, and between 1 and 1.5 m above mean sea level in height. The highest point in the Maldives is an unnamed location on the Wilingili Island in the Addu Atoll at 2.4 m. The longest island is Hithadhoo at 8 km in the Addu Atoll. Each atoll has approximately five to ten inhabited islands and approximately 20 to 60 uninhabited islands. Overall, approximately 200 of the islands are inhabited.

2.4 Climate of the Maldives

The Maldives has an equatorial climate with high humidity and average temperatures between 27º and 29º Celsius all year. Because of the Maldives' proximity to the equator, the monsoon seasons are not as well defined as they are in Sri Lanka. The monsoons are best defined in the northern part of the country. This region has distinct monsoon seasons including the strong southwest monsoon from June through September and a noticeable northeast monsoon from December through February. However, at the southern end of the Maldives on Addu Atoll, there is not as strong a monsoon signal with winds speeds fairly uniform throughout the year. The average annual precipitation ranges increase from north to south with between 1500 mm and 2000 mm in the northern part of the country to around 2500 mm at Gan Island on the Addu Atoll.

Maldives
Political Base Map



Legend

■ Town, Village or **Capital**

50 0 50 100 150 200 Kilometers

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24-JUN-2003 1.2.4

Figure 2-4

3.0 Fundamentals of Wind Resource Estimation

3.1 Introduction

This section introduces the basic concepts of wind resource estimation and presents some of the data sources that can be used in an assessment study.

Wind resource assessment studies can be placed into three basic categories:
- Preliminary area identification
- Area wind resource evaluation
- Micrositing

NREL's wind resource atlases are useful for the first two categories but do not contain the detailed information needed for micrositing studies. Details about micrositing and wind monitoring programs can be found in the *Wind Resource Assessment Handbook* (NREL/AWS Scientific, 1997).

3.2 Wind Speed and Direction

Wind speed is the simplest representation of the wind at a given point. Anemometers or other calibrated instruments measure wind speed. Wind speeds can be calculated as an average or expressed as an instantaneous value. Wind speed averaging intervals commonly used in resource assessment studies include 1- or 2- minute (weather observations), 10-minute (often used in the wind monitoring programs), hourly, monthly, and yearly periods. It is important to know the measurement height for a given wind speed because of the variation of wind speed with height. It is also desirable to know the exposure of a particular location to the prevailing winds, because nearby obstacles such as trees and buildings can reduce the wind speed.

Wind direction is measured with a wind vane, usually located at the same height as the anemometer. Knowledge of the prevailing wind direction is important in assessing the available resource. Correct alignment of the wind vane to a reference direction is important to accurately measure the wind direction, but it is not always properly aligned. Wind direction observations at meteorological stations are often based on a 36-point compass (every 10 degrees). Some wind direction data are expressed in less precise 8-point (every 45 degrees), 12-point (every 30 degrees), or 16-point (every 22.5 degrees) intervals.

The wind direction distribution is often presented as a wind rose; a plot of frequency of occurrence by direction. Wind roses can also represent quantities such as the average speed or the percent of the available power for each direction.

3.3 Wind Speed Frequency Distribution

The wind speed frequency distribution characterizes the wind at a given location in two ways. First, the frequency distribution determines how often a given wind speed is observed at the location and second, it identifies the range of wind speeds observed at that location. This analysis is often accomplished by sorting the wind speed observations into 1 meter per second (m/s) bins and computing the percentage in each bin. The wind speed distribution is important because sites with identical average wind speeds but different distributions can result in substantially different available wind resources. These differences can be as great as a factor of two or three.

3.4 Weibull Distribution Function

The wind speed frequency distribution in many areas can be closely approximated by the Weibull Distribution Function. The Weibull Function is defined as:

$$f(V) = (k/c)(V/c)^{k-1} \exp(-V/c)^{k}$$

where:

- $f(V)$ = the Weibull probability density function, the probability of encountering a wind speed of V m/s;
- c = the Weibull scale factor, which is typically related to the average wind speed through the shape factor, expressed in m/s;
- k = the Weibull shape factor, which describes the distribution of the wind speeds.

Detailed explanations of the Weibull Distribution Function and its application are available in many texts, such as that by Rohatgi and Nelson (1994).

3.5 Wind Power Density

The wind resource at a site can be roughly described by the mean wind speed, but the wind power density provides a truer indication of a site's wind energy potential. Wind power density expresses the average wind power over one square meter (W/m^2). The power density is proportional to the sum of the cube of the instantaneous (or short-term average) wind speed and the air density. As a result of this cubic term, two sites with the same average wind speed but different distributions can have very different wind power density values. The wind power density, in units of W/m^2, is computed by the following equation:

$$\mathbf{WPD} = \frac{1}{2n} \sum_{i=1}^{n} \rho \cdot v_i^3$$

where

- WPD = the wind power density in W/m^2;
- n = the number of records in the averaging interval;
- ρ = the air density (kg/m^3) at a particular observation time;
- v_i^3 = the cube of the wind speed (m/s) at the same observation time.

This equation should only be used for individual measurement records (hourly, 10-minute, etc.) and not for long-term average records that use monthly or yearly values. If used with long-term averages, this equation will underestimate the wind power density, because long-term averages do not include most of the higher-speed records that would more accurately calculate the wind power density.

The air density term (kg/m^3) is dependent on temperature and pressure and can vary by 10% to 15% seasonally. If the site pressure and temperature are known, the air density can be calculated using the following equation:

$$\rho = \frac{P}{R \cdot T}$$

where

ρ = the air density in kg/m^3;
P = the air pressure (Pa or N/m^2);
R = the specific gas constant for air (287 J/kg·K);
T = the air temperature in degrees Kelvin (°C+273).

If site pressure is not available, air density can be estimated as a function of site elevation (z) and temperature (T) as follows:

$$\rho = \left(\frac{P_0}{R \cdot T}\right) \varepsilon^{\left(\frac{-g \cdot z}{R \cdot T}\right)}$$

where

ρ = the air density in kg/m^3;
P_0 = the standard sea level atmospheric pressure (101,325 Pa), or the actual sea-level adjusted pressure reading from a local airport;
g = the gravitational constant (9.8 m/s^2);
z = the site elevation above sea level (m).

Substituting in the numerical values for P_0, R, and g, the resulting equation is:

$$\rho = \left(\frac{353.05}{T}\right) \varepsilon^{-0.034\left(\frac{z}{T}\right)}$$

This air density equation can be substituted into the wind power density (WPD) equation to determine each of the instantaneous or multiple average values.

3.6 Wind Shear and the Power Law

The wind shear is a description of the change in horizontal wind speed with height. The magnitude of the wind shear is site-specific and dependent on wind direction, wind speed, and atmospheric stability. By determining the wind shear, one can extrapolate existing wind speed or wind power density data to other heights. The following form of the power law equation can be used to make these adjustments:

$$U = U_0 (z/z_0)^{\alpha} \qquad \text{[Wind Speed]}$$

$$WPD = WPD_0 (z/z_0)^{3\alpha} \qquad \text{[Wind Power Density]}$$

where

U = the unknown wind speed at height z above ground;
U_0 = the known speed at a reference height z_0;
WPD = the unknown wind power density at height z above ground;
WPD_0 = the known wind power density at a reference height z_0;
α = the power law exponent.

An exponent of 1/7 (or 0.143), which is representative of well-exposed areas with low surface roughness, is often used to extrapolate data to higher heights.

3.7 Sources of Wind Data

3.7.1 Surface Observations

Surface meteorological data are available from many sources. Most countries have a meteorological agency that collects data from a network of stations across the country. Other data may be available from regional agencies, scientific organizations, power utilities, and private companies.

For accurate wind resource estimation, wind speed and direction must be included, but temperature and pressure can also be helpful. A site's exposure, anemometer height, local topography, and site maintenance history are also quite useful.

Wind speeds at some sites decrease steadily over a period of years (the "disappearing winds" effect). This trend can be caused by new building construction or tree growth near the site or by a lack of anemometer maintenance. Extra quality control procedures must be applied in analyzing data from sites with this wind speed trend.

3.7.2 Upper-Air Observations

Upper-air stations measure the meteorological properties of the atmosphere above the surface by launching balloons, usually between one and four times daily. Pilot balloons, which are un-instrumented balloons that are tracked through theodolites, comprise the simplest upper-air observations. Pilot balloon observations can only estimate wind speed and direction. Radiosonde (or rawinsonde) packages of instruments that relay atmospheric conditions to the base station by radio make more elaborate and accurate measurements. The instrumented packages measure temperature, pressure, and humidity in addition to wind speed and direction.

3.7.3 Satellite Ocean Wind Measurements (SSMI)

The SSMI, which is part of the U.S. Defense Meteorological Satellite Program, provide 10-m ocean wind speed measurements. The data set provides much more uniform and detailed coverage of oceanic wind speeds than historical ship data. Comparisons of satellite-derived winds with ship observations along major shipping routes indicate consistent results. NREL currently has 15 years of SSMI data covering the period 1988 through 2002.

3.7.4 Computer Model Climatic Data

Computer weather prediction models can generate climatic data, including wind speed and direction. These computer models analyze meteorological data from many sources and generate sets of meteorological parameters at regular grid points. The large-scale model output covers the entire globe and usually includes meteorological data at the surface and for a number of levels above the surface. The horizontal distance between grid points for the large-scale data is often greater than 200 kilometers (km). Meteorological output from what is referred to as mesoscale computer models covers specified regions. The data grid points from the mesoscale model are much closer together than those from the large-scale data with the horizontal distance ranging from about 2 km to 20 km. Computer model data are valuable for assessment work in data-sparse regions of the world. The major drawback of depending entirely on computer model data is that output data at a particular grid point can be strongly influenced by input meteorological data that may not be representative of the climatic conditions in the study region. Good meteorological judgment is required when computer model data are used in assessment work.

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4.0 Wind Resource Methodology and Mapping System

4.1 Introduction

This section describes the methodology used to analyze and evaluate the meteorological data used for this resource assessment and the mapping system used to generate the resource maps. Both components are crucial for the production of a wind resource atlas that is accurate enough to stimulate the development of wind energy in the study area.

NREL uses a GIS-based wind resource mapping technique to produce the maps presented in this atlas. This technique was also used in the production of wind atlases for the Philippines (Elliott et al. 2001), the Dominican Republic (Elliott et al. 2001), Mongolia (Elliott et al. 2001), and Southeast China (Elliott et al. 2002), and maps of specific regions of Chile, Indonesia, Mexico, and the United States (Schwartz, 1999; Elliott et al., 1999; Schwartz and Elliott, 2001; Elliott, 2002). NREL developed the mapping system with two primary goals in mind:

1) To produce a more consistent, detailed analysis of the wind resource, particularly in areas of complex terrain
2) To generate user-friendly, high-quality maps.

4.2 Methodology

4.2.1 Data Evaluation and Analysis

4.2.1.1 Initial Approach

The quality of the meteorological input depends on understanding important wind characteristics in the study region such as the interannual, seasonal, and diurnal variability of the wind and the prevailing wind direction. NREL used innovative assessment methods on existing climatic data sets to develop a conceptual understanding of these key wind characteristics. These data sets, obtained from U.S. sources such as the National Climatic Data Center and National Center for Atmospheric Research and supplemented with data sets obtained from Sri Lanka and the Maldives, are maintained at NREL as part of its global archive. Much of the surface and upper-air (weather balloon) data used in this project had a long period of record (10 to 20 years or more). NREL's approach depends on the critical analysis of all the available (surface meteorological and upper-air) climatic data for Sri Lanka and the Maldives and the surrounding areas. NREL used a comprehensive data-processing package to convert the data to statistical summaries of the wind characteristics for many surface stations, upper-air locations, and ocean areas. These summaries were used to evaluate the regional wind characteristics.

4.2.1.2 Surface Data Evaluation

Years of work at NREL revealed many problems with the available land-based surface wind data collected at meteorological stations in much of the world. Problems associated with observations taken at the meteorological stations include a lack of information on anemometer height, exposure, hardware, maintenance history, and observational procedures. These problems can cause the quality of observations to be extremely variable. In addition, many areas of the world with good or excellent potential wind resource areas have very little or no meteorological station data to help assess the level of the available wind resource.

NREL took specific steps in its evaluation and analysis to overcome these problems. Site-specific products were screened for consistency and reasonableness. For example, the interannual wind speeds were evaluated to identify obvious trends in the data or periods of questionable data. Only representative data periods were selected for the assessment. The summarized products were also cross-referenced to select the sites that appeared to have the best exposure to the prevailing wind. These sites were used to develop an understanding of the wind characteristics of the study region.

4.2.1.3 Upper-Air Data Evaluation

Upper-air data can be useful in assessing the regional wind resource in several ways. First, upper-air data can be used to estimate the resource at low levels just above the surface. The low-level resource estimation is quite important in areas where surface data are sparse or not available. Second, upper-air data can be used to approximate vertical profiles of wind speed and power. The vertical profiles are used to extrapolate the quantity of wind resource to elevated terrain features and to identify low-level wind speed maximums that can enhance the wind resource at turbine hub-height.

NREL generated summaries of wind speed and wind power at specific pressure and height levels using upper-air data, as well as monthly and annual average vertical profiles of wind speed and power. One problem that continually occurs in the evaluation of upper-air data is that many of the locations where the balloons are launched are blocked from the ambient wind flow by high terrain. Using vertical profiles from the "blocked" locations can be misleading because the profiles only represent conditions at the upper-air station and will not apply throughout the region of interest. Therefore, NREL's analysis of the upper-air data uses vertical profiles that we judge to be representative of the ambient wind flow in a particular region.

4.2.1.4 Goals of Data Evaluation

The goal of a critical analysis and evaluation of surface and upper-air data is to develop a conceptual model of the physical mechanisms on a regional and local scale that influence the wind flow. When there is conflicting wind characteristic data in an analysis region, the preponderance of meteorological evidence from the region serves as the basis for the conceptual model. Several NREL papers (Elliott, 2002; Schwartz and Elliott, 1997; Elliott and Schwartz, 1998; Schwartz, 1999) describe the integration, analysis, and evaluation of meteorological data sets typically used for wind resource assessments.

The critical data analysis and the conceptual model are particularly important, because a key component of NREL's wind mapping system requires that empirical adjustments be made to the wind power values before the final maps are produced. The conceptual understanding developed by the critical analysis of the available data guides the development of empirical relationships that are the basis of algorithms used to adjust the wind power. This empirical approach depends on an accurate ambient wind profile of the few hundred meters closest to the surface and being able to adjust it down to the surface layer. A prime advantage of this method is that NREL can produce reliable wind resource maps without having high quality surface wind data for the study region.

4.2.2 Wind Power Classifications

The values on the wind resource maps in the atlas are based on the wind power density, not wind speed. Wind power density is a better indicator of the available resource because it incorporates the combined effects of the wind speed frequency distribution, the dependence of the wind power on air density, and the cube of the wind speed.

Seven wind power classifications, based on ranges of wind power density, were used for the Sri Lanka maps. Each of the classifications was qualitatively defined for utility-scale applications (poor to excellent). In general, locations with an annual average wind resource greater than 400 W/m^2 or approximately 7.0 m/s at 50 m above ground are the most suitable for utility-scale applications.

Wind energy applications in the Maldives will be primarily for resort and village power. Five wind power classifications qualitatively defined for large-scale (greater than 50 kW of installed capacity) and small-scale (less than 50 kW) applications were used for the Maldives wind map. Resort and village power applications are viable for lower levels of resource than utility-scale applications, particularly for locations with high-cost diesel generation. In the Maldives, resort and village wind power applications may be viable with resources greater than 200 W/m^2 or approximately 5.6 m/s at 50 m above ground.

4.3 Description of Mapping System

NREL's mapping system uses GIS mapping software. The main GIS software, ArcInfo®, is a powerful and complex package that features a large number of routines for scientific analysis. None of the ArcInfo® analysis routines are specifically designed for wind resource assessment work; therefore, NREL's mapping technique requires extensive programming in ArcInfo® to create combinations of scientific routines that mimic direct wind resource assessment methods. For more information about GIS and wind energy research at NREL, see Heimiller and Haymes (2001).

The mapping system is divided into three main components: the input data, the wind power adjustments, and the output section that produces the final wind resource map. These components are described below.

4.3.1 Input Data

The two primary model inputs are digital terrain data and meteorological data. The elevation information consists of digital elevation model (DEM) terrain data that divide the analysis region into individual grid cells, each having its own unique elevation value. The U.S. Geological Survey's Earth Resource Observing Satellite Data Center produced updated DEMs for most of the world from previously classified U.S. Department of Defense data and other sources. The data sets have a resolution of 1 km^2 and are available for large parts of the world. This represents a significant improvement in elevation data used by the mapping system. The model previously relied on the Digital Chart of the World (DCW) 1:1,000,000-scale maps and 305 m (1,000 ft) elevation contours. A reliable DEM for the Maldives was not available because of the small sizes of the individual islands. Therefore, information from the DCW maps was used for the Maldives model run.

Meteorological inputs to the mapping system come in two phases. The first phase provides wind power data for each grid cell obtained via output from a mesoscale numerical model. The second phase, following the data screening process, provides the appropriate vertical profiles of wind power density and wind power roses that express the percentage of total potential power from the wind by direction. The vertical profiles are broken down into 100-m intervals centered every 100 m above sea level. The wind power rose is used to determine the degree of exposure of a particular grid cell to the power-producing winds.

Numerical model data were used as one of the elements for the Sri Lanka meteorological input. The input for the Maldives did not include mesoscale model data but was based on the wind power roses and vertical profiles derived from NREL's in-house data sets. These inputs and the original wind power grid are incorporated as Arc/Info® compatible files and used in the power adjustment algorithms.

4.3.2 Wind Power Calculations

The wind power calculation methodology is presented in Section 3.5. TrueWind Solutions (TWS), a U.S. company in Albany, New York, provided to NREL the initial wind power density values for each grid cell in Sri Lanka. TWS used its proprietary MesoMap system (Brower et al, 2001) to calculate the wind power density values. The MesoMap system consists of the MASS (a mesoscale model) and WindMap (a mass conserving wind-flow model).

The MASS model simulated weather conditions over Sri Lanka and the surrounding regions for 366 days randomly selected from a 15-year period. The random sampling was stratified so that each month and season was represented equally. Each simulation generates wind and other meteorological variables throughout the model domain for a particular day and stores the information at hourly intervals. The simulations use a variety of meteorological and geophysical data. MASS uses climatic data to establish the initial conditions for each simulation as well as lateral boundary conditions for the model. The model determines the evolution of atmospheric conditions within the study region during each simulation.

The main geophysical inputs into MASS are elevation, land cover, greenness of vegetation, and soil moisture. The MASS translates both land cover and vegetation greenness into important surface parameters such as surface roughness.

The MASS was run with a horizontal resolution of 2 km. After all the simulations were completed, the results were processed into summary data files that were input into the WindMap model. WindMap then calculated the wind power density down to the final 400 m by 400 m grid cell resolution.

The base wind power density values for the Maldives were based on data from NREL's in-house meteorological and geographic data sets. The final wind resource map power values are calculated from the wind power adjustment modules in the NREL mapping system. Only islands that were included on the DCW 1:1,000,000-scale maps appear on NREL's maps of the Maldives. NREL applied a 3-km buffer around each island to better highlight the wind power values.

The wind power adjustment modules in NREL's wind mapping system use different routines depending on the results of NREL's data evaluation. Power adjustment modules can be activated to account for blocking of the ambient flow by terrain; the relative elevation of particular regions; acceleration and enhanced wind flow areas; proximity to lakes, oceans, or other large water bodies; or any combination of the above. The power adjustment routines use general topographical descriptions classified as either complex terrain (hills and ridges), complex terrain with large flat areas present, or areas designated as flat. The adjustment to the initial wind power density depends on which routines are activated during the final mapping run.

4.3.3 Mapping Products

The primary output of the mapping system is a color-coded wind power map in units of W/m^2 and equivalent mean wind speed for each individual grid cell. The wind power classification scheme for the Sri Lanka maps is presented in Table 4-1 and the power classification scheme for the Maldives is presented in Table 4-2. In this atlas, the 50-m height above ground level (agl) was used as the reference level.

The wind power is shown only for those grid cells that meet certain slope requirements. A grid cell is excluded if the slope of the terrain is too steep. The slope of the terrain in a grid cell must be less than or equal to 20% to be included in the wind power calculations. The wind power values for Sri Lanka are estimates based on the surface roughness for each grid cell derived from the MASS model output. No surface roughness data were available for the Maldives, so the wind power values are for exposed locations.

Table 4.1. Sri Lanka Wind Power Classification

Class	Resource Potential (Utility-Scale)	Wind Power Density (W/m^2) @ 50 m agl	Wind Speed [(a)] (m/s) @ 50 m agl
1	Poor	0 – 200	0.0 – 5.6
2	Marginal	200 – 300	5.6 – 6.4
3	Moderate	300 – 400	6.4 – 7.0
4	Good	400 – 500	7.0 – 7.5
5	Excellent	500 – 600	7.5 – 8.0
6	Excellent	600 – 800	8.0 – 8.8
7	Excellent	> 800	> 8.8

(a) Mean wind speed is estimated assuming a sea level elevation and a Weibull distribution of wind speeds with a shape factor (k) of 2.0. The actual mean wind speed may differ from these estimated values by as much as 20%, depending on the actual wind speed distribution (or Weibull k value) and elevation above sea level.

Table 4.2. Maldives Wind Power Classification

Resource Large	Potential Small	Wind Power Density (W/m^2) @ 50 m agl	Wind Speed [(a)] (m/s) @ 50 m agl
Fair	Moderate	225 – 250	5.8 – 6.0
Fair	Moderate	250 – 275	6.0 – 6.2
Fair	Moderate	275 – 300	6.2 – 6.4
Moderate	Good	300 – 325	6.4 – 6.5
Moderate	Good	325 – 350	6.5 – 6.7

[(a)] Mean wind speed is estimated assuming a sea level elevation and a Weibull distribution of wind speeds with a shape factor (k) of 2.0. The actual mean wind speed may differ from these estimated values by as much as 20%, depending on the actual wind speed distribution (or Weibull k value) and elevation above sea level.

The mapping system output uses software to produce the proper map projection for the study region, and to label the map with useful information such as a legend, latitude and longitude lines, locations of meteorological and other wind measurement stations, important cities, and a distance scale. The DEM data can also be used to create a color-coded elevation map, a hill-shaded relief map, and a map of the elevation contours. When combined with the wind power maps, these products provide the user with a three-dimensional image of the distribution of the wind power in the analysis region.

4.3.4 Limitations of Mapping Technique

The mapping technique has several limitations, the first of which is the resolution of the DEM data. Significant terrain variations can occur within the DEM's 1 km^2 area; thus, the wind resource estimate for a particular grid cell may not apply to all areas within the cell. A second potential problem lies with the extrapolation of the conceptual model of the wind flow to the analysis region. Many complexities in the wind flow make this an inexact methodology. The complexities include the structure of low-level jets and their interaction with the boundary layer; localized circulations, such as land-sea breezes, and mountain-valley flows; and channeling effects in areas of steeply sloping terrain. Finally, the power estimates in Sri Lanka are based on each grid cell's surface roughness based on the MASS output and in the case of the Maldives for exposed areas. Because the geophysical input to MASS is not 100% accurate, errors in the surface roughness estimate can occur and consequently, the estimate of wind resource for particular locations in Sri Lanka.

Any trees or buildings will minimally affect the 50-m wind power values on the small islands of the Maldives. However, treed or other areas with obstructions will have considerably reduced resource at 20-m or 30-m compared to the 50-m values.

5.0 Wind Resource Data for Sri Lanka and the Maldives

5.1 Introduction

An accurate wind resource assessment depends on the quantity and quality of the input data. NREL reviews many sources of wind data and previous wind assessments as part of its overall evaluation. Several global data sets maintained at NREL, including surface and upper-air observations spanning many years of record, were used in this assessment. Because the quality of data in any particular data set can vary, and high-quality data can be quite sparse in many regions of the world, multiple data sets are used. Each data set plays an integral role in the overall assessment. In this section, we summarize the data sets used to prepare the wind resource mapping activity for Sri Lanka and the Maldives. All data sets were analyzed and evaluated in accordance with the procedures outlined in Section 4.0.

5.2 Surface Data

High quality surface wind data from well-exposed locations can provide the best indication of the magnitude and distribution of the wind resource in the region. Studies by NREL and others in many different regions of the world have found that the quality of surface wind data from meteorological stations varies and is often unreliable for wind resource assessment purposes.

The following sections present a summary of the surface data sets obtained and examined in the assessment.

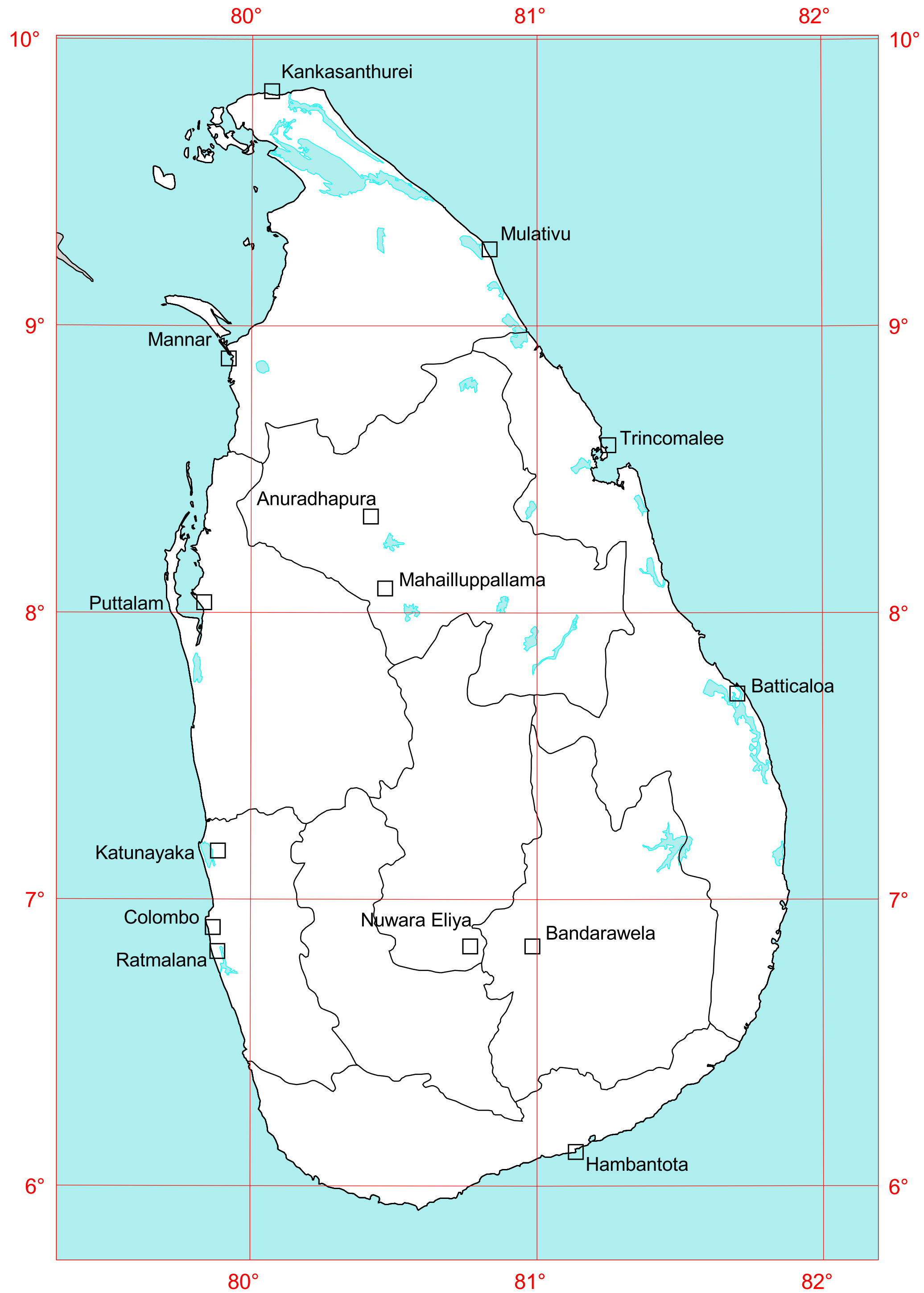
5.2.1 Historical Meteorological Data – Sri Lanka

Data from 14 long-term meteorological stations in Sri Lanka were obtained from the Department of Meteorology of Sri Lanka. The data consisted of monthly average wind speeds over periods from 10 to 50 years. Figure 5.1 shows the location of these stations. Because frequency distribution information was not available, it was impossible to compute wind power densities for these sites. The data were useful, however, in examining long-term trends in wind speed. Stations and their wind speeds are listed in Table A.1.

The quality of these wind data is largely unknown because of the lack of information on equipment maintenance and exposure to the wind. The graphs in Appendix A show that some of the stations in Sri Lanka had obvious trends or abrupt changes in the historical wind speeds recorded on an interannual basis. Figure 5.2 shows an example of the "disappearing wind syndrome," as evidenced by the downward trend in the historical wind speeds at four meteorological stations. New construction, growth of trees around the meteorological station, or degradation of the measurement equipment may have caused the decrease in wind speeds. The large reductions in wind speeds at these stations correspond to even greater percentage reductions in the wind power density. For these reasons, the long-term historical average for many stations is not a reliable indicator of the wind resource, particularly where obvious trends or abrupt changes are evident in the historical wind speeds.

High-quality surface data from a wind measurement station at Rameswaram, India (Mani, 1994) proved most useful for evaluating the resource for nearby areas of Sri Lanka including Mannar Island and northward where surface data in Sri Lanka were lacking.

Sri Lanka - Department of Meteorology Measurement Sites



25 0 25 50 75 100 125 Kilometers

Total Stations in Sri Lanka = 14

Mean monthly wind speeds for the meteorological stations were provided by the Sri Lanka Department of Meteorology.

Legend

☐ Wind Measurement Site

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Figure 5-1

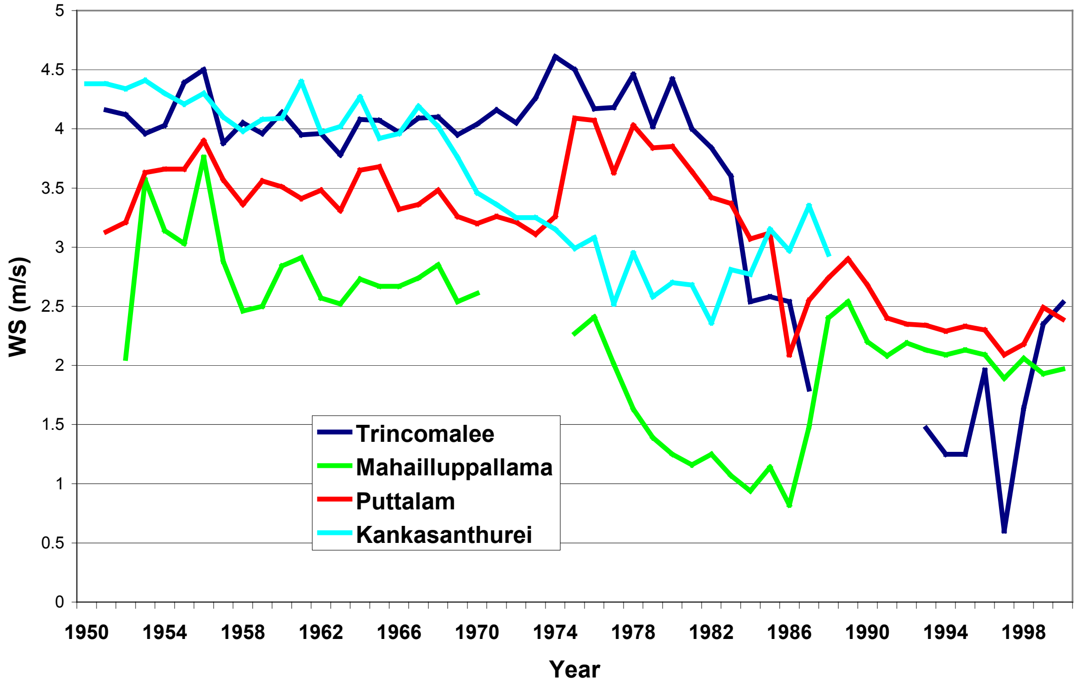


Figure 5.2 Disappearing Winds at Sri Lanka Meteorological Stations

5.2.2 Historical Meteorological Data – Maldives

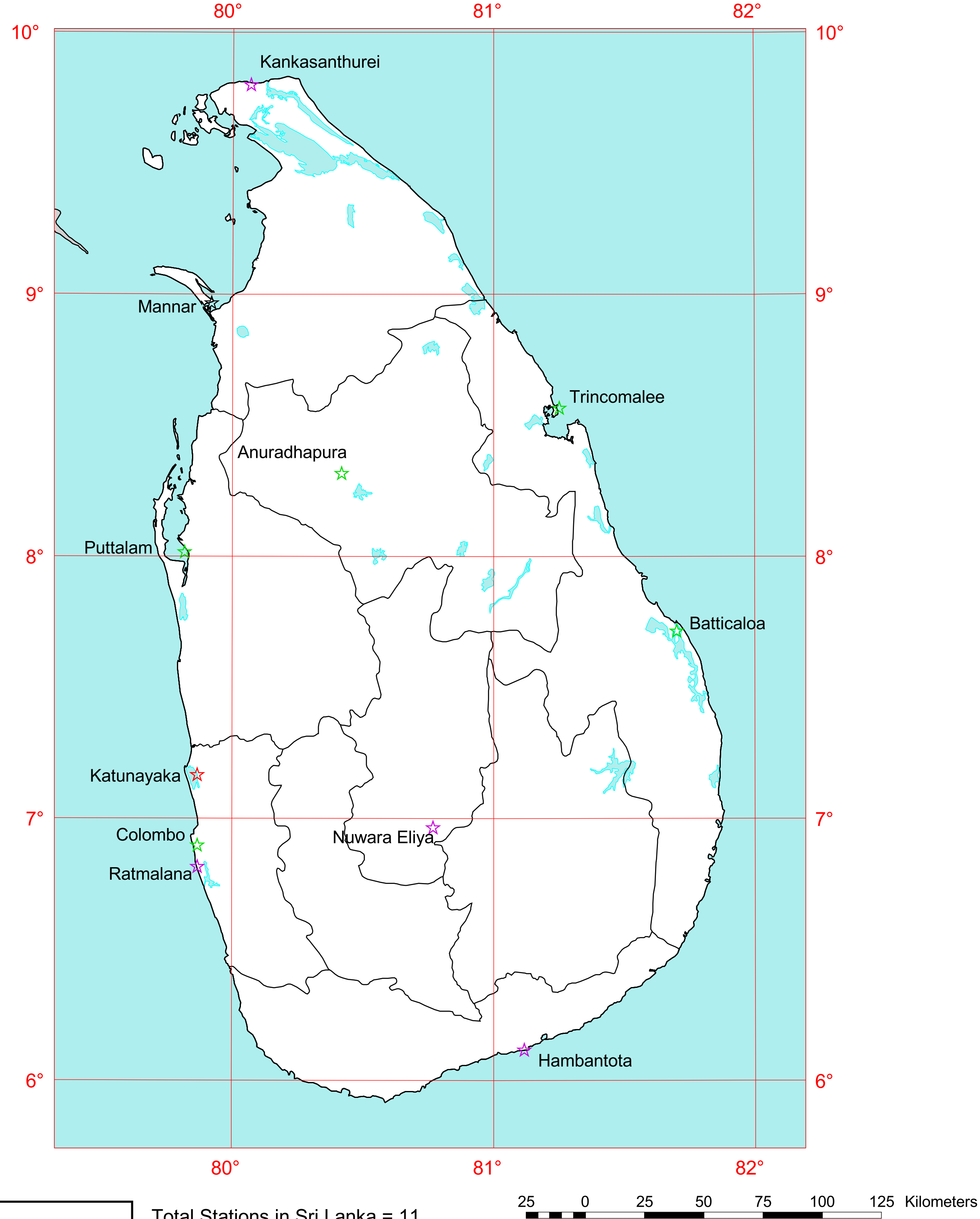
NREL obtained meteorological station data provided by the Department of Meteorology of the Maldives (Department of Meteorology, 2002). This data set contained monthly wind speed data from the four stations in NREL's DATSAV2 data set (see below), but covered a different (but overlapping) period of record of 10 to 15 years. As with the Sri Lanka long-term data, it was not possible to compute wind power densities for these sites. Table A.2 shows the stations, their period of record and average wind speeds. Because of the shorter period of record of this data set, trends such as the "disappearing winds" are more difficult to identify.

5.2.3 DATSAV2 Data

The DATSAV2 global climatic database obtained from the NCDC contains the surface weather observations, transmitted via the Global Telecommunications System (GTS), from first-order meteorological stations throughout the world. Meteorological parameters such as wind speed, wind direction, temperature, pressure and altimeter setting are used to create statistical summaries of wind characteristics. A unique six-digit number based on the World Meteorological Organization (WMO) numbering system identifies each station in the DATSAV2 data set.

There are 14 stations in Sri Lanka and 4 in the Maldives in the DATSAV2 climatic data set. Of these, 11 of the Sri Lanka and all of the Maldives stations have sufficient meteorological data to analyze. Figure 5.3 shows the locations and number of observations for the Sri Lanka stations, while Figure 5.4 shows the information for the Maldives stations.

Sri Lanka - GTS Surface Meteorological Stations



Meteorological Stations
Total Observations

- ☆ 40,000 to 70,000
- ☆ 20,000 to 40,000
- ☆ 10,000 to 20,000
- ☆ 5,000 to 10,000
- ☆ 1,000 to 5,000

Total Stations in Sri Lanka = 11

The Global Telecommunication System (GTS) surface meteorological stations are part of NREL's global database.

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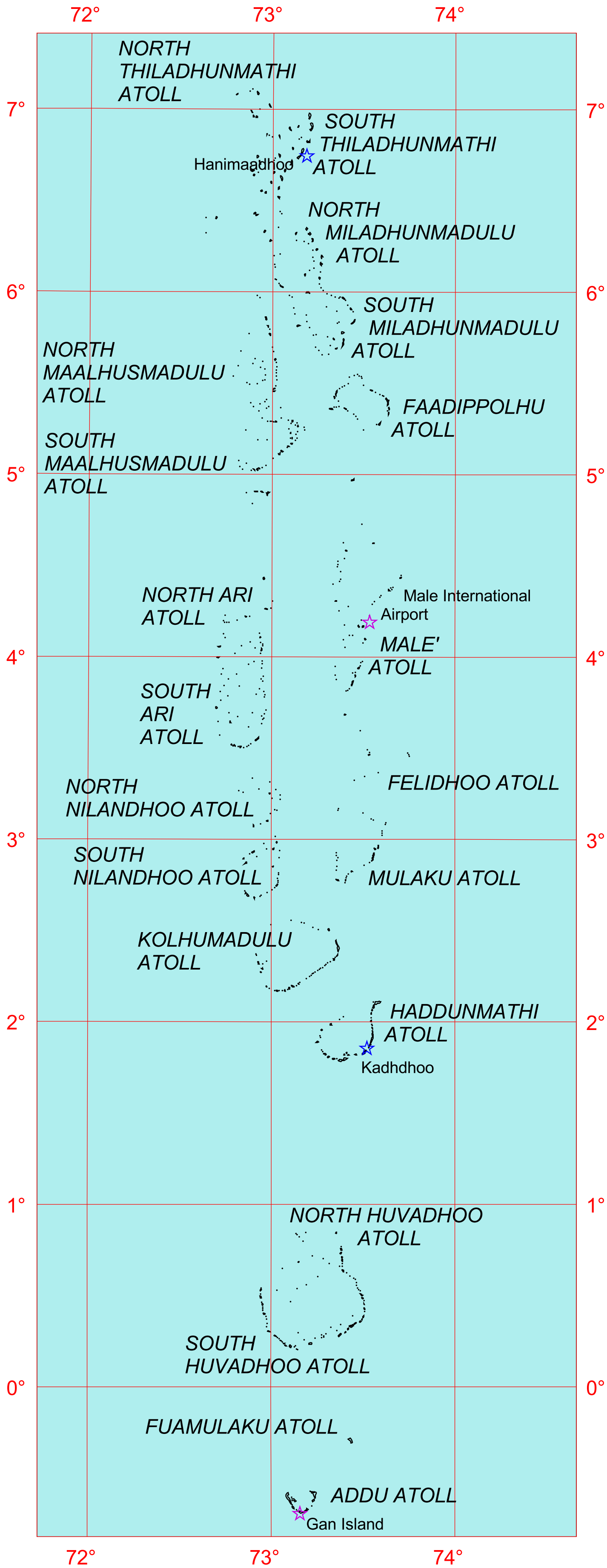
Figure 5-3

Maldives
Department of Meteorology/GTS Surface Meteorology Stations



The Global Communication System (GTS) surface meteorological stations are part of NREL's global database. The Meteorological Department of the Maldives provided summaries of wind data for these surface meteorological stations.

Total Stations in The Maldives = 4

Meteorological Stations
Total Observations

- ☆ 20,000 to 40,000
- ☆ 10,000 to 20,000
- ☆ 5,000 to 10,000

50 0 50 100 150 200 Kilometers

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20-JUN-2003 1.3.4

Figure 5-4

The number of observations at the individual sites for each year and from year to year are highly variable. The stations in Sri Lanka and the Maldives typically recorded data every 3 hours but in some cases, the data were recorded only 3 times a day.

The processed data records for each of these 15 stations (11 Sri Lanka and 4 Maldives) included monthly and annual averages of wind speed and wind power. Table B.1 provides location data and wind speed summaries for these stations and graphical summaries for selected stations in Appendix B. These data are useful for evaluating the interannual and monthly variability, the diurnal distribution of wind speed and wind power, and the joint frequency of wind speed and direction.

5.2.4 CEB Wind-Monitoring Program Data

Over the past 15 years, the Ceylon Electricity Board (CEB) has conducted several wind measurement programs in Sri Lanka. The first, an assessment at 10 stations conducted from 1989 to 1992, included 9 stations in the southeast coastal area and one station in the highlands (Ceylon Electricity Board, 1992). Anemometers were installed at 10-m, 15- m, and 20-m heights above ground and a wind direction sensor was installed at 20 m.

From 1996–1999, CEB measured data at 5 more sites using 33- or 34-m towers. Four of these sites were in the southeast coastal region, and the fifth was located on the west coast. Anemometers were located at 33 m or 34 m, 20 m, and 10 m, and the wind vane was installed at 33 m or 34 m.

From 1999–2002, CEB conducted a wind measurement program in the Puttalam and central highland regions of Sri Lanka (Ceylon Electricity Board, 2002). This study collected data at 8 sites, with anemometers mounted at 40 m, 20 m, and 10 m and a wind vane at 40 m.

All 23 CEB stations are listed in Table 5.1, and a map of the station locations is shown in Figure 5.5.

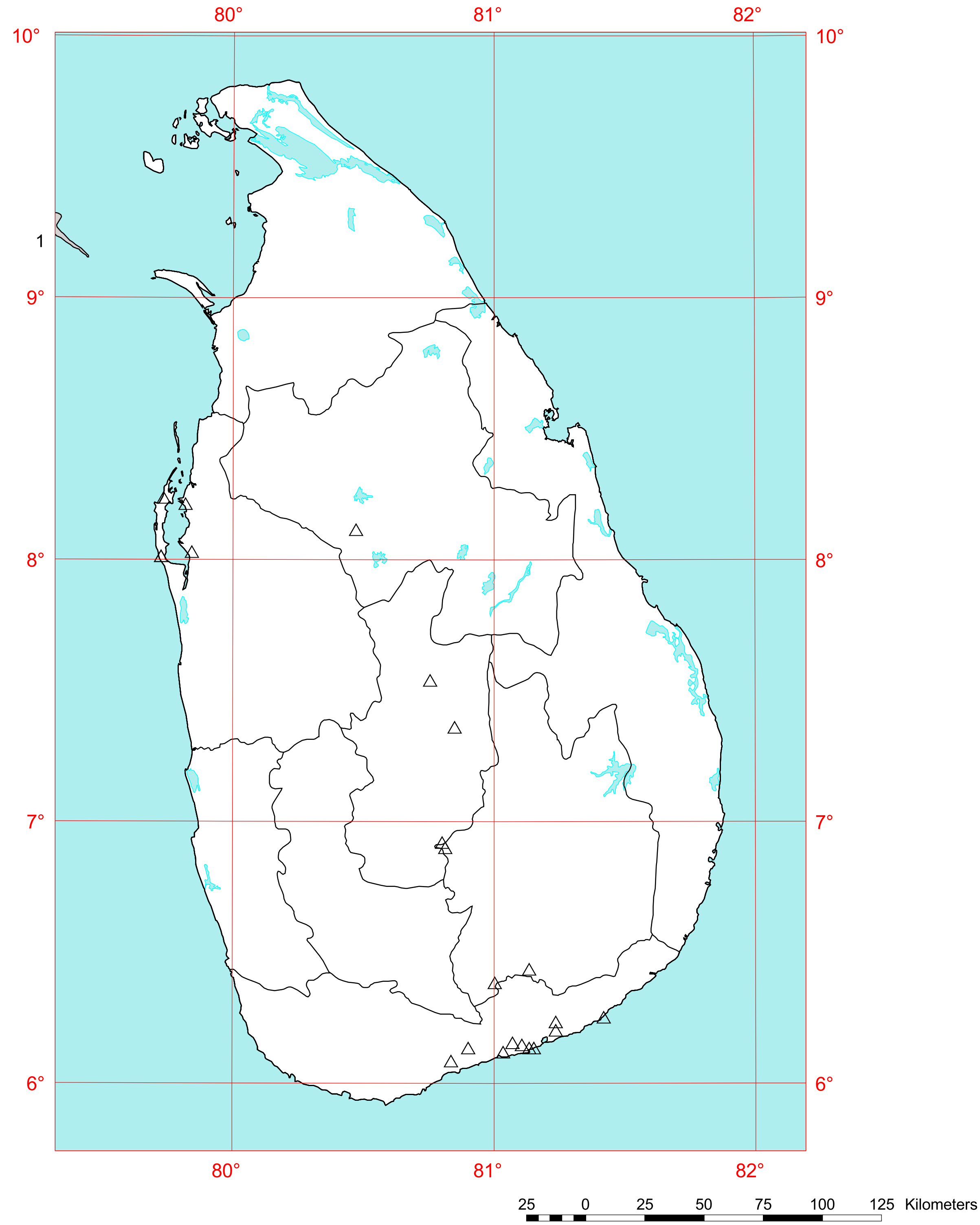
NREL obtained and processed the hourly wind speed and wind direction data presented in Table 5.1 with the power measured at each site. Appendix C contains graphs of annual and monthly summaries for specific wind statistics for selected stations. These include monthly average wind speed and power, average wind speed and power by hour of the day, frequency and speed by wind direction, and frequency of wind speed and the percent of power by speed.

5.3 Upper-Air Data

The upper-air data, consisting of profiles of wind speed and wind direction, are an important meteorological input parameter for the wind-mapping model. Upper-air data also provide an estimate of the wind resource just above the surface-layer and contribute to the understanding of the vertical distribution of the wind resource. This is useful in estimating the winds on elevated terrain features and the wind resource at exposed locations without reliable surface wind observations.

NREL's in-house data sets include both observational and computer model-derived upper-air information. The following upper-air data sets were available for the assessment.

Sri Lanka - Ceylon Electricty Board Measurement Sites



Total Stations in Sri Lanka = 22

Legend

△ CEB Wind Measurement Site

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Figure 5-5

Table 5.1 Ceylon Electricity Board Wind Measurement Sites

Name	An Ht	Lat	Lon	From	To	NObs	PCD	WS	WPD
Bundala	20	6 12	81 14	1990/04	1993/12	28373	86%	5.6	194
Hambantota Wv. Trp.	20	6 08	81 09	1990/04	1992/12	20737	85%	5.9	218
Hambantota Met. Stn	20	6 08	81 08	1991/05	1993/05	16772	92%	6.7	291
Palatupana	20	6 15	81 25	1990/06	1991/05	8581	99%	5.8	218
Pattiyapola	20	6 05	80 50	1990/01	1992/06	20537	94%	3.8	71
Ambalantota	20	6 07	81 02	1990/03	1991/02	8657	98%	4.0	75
Sevanagala	20	6 23	81 00	1990/07	1991/12	12048	95%	4.6	142
Tanamalwila	20	6 26	81 08	1990/06	1991/07	9038	89%	3.6	85
Eraminiyaya	20	6 08	80 54	1991/01	1992/08	13464	92%	3.6	52
Sita Eliya	20	6 55	80 48	1991/03	1992/10	13368	92%	5.2	198
Weerawila	33	6 14	81 14	1996/12	1997/03	2591	100%	4.3	80
Kajuwatta	34	6 09	81 06	1997/06	1999/11	21435	99%	5.1	137
Mirrijjawila	34	6 09	81 04	1996/11	1999/11	24219	92%	4.9	148
Hambantota Met. Stn.	33	6 09	81 04	1996/10	1997/12	7430	74%	6.4	316
Narakkalliya Old	34	8 01	79 43	1998/03	1999/09	12002	90%	7.4	372
Narakkalliya New	40	8 01	79 43	2000/01	2001/12	16759	97%	7.0	324
Puttalam Met.	40	8 02	79 50	2000/09	2001/12	11071	100%	5.2	135
Karathivu	40	8 13	79 48	2000/01	2001/12	16879	98%	6.4	266
Wellammalal	40	8 14	79 44	2000/02	2000/08	4415	100%	5.5	205
Ratninda	40	7 32	80 04	2000/11	2001/12	59323	98%	3.8	113
Hare Park	40	7 22	80 51	2000/11	2002/05	75069	95%	4.4	154
Ambewela	40	6 54	80 48	2000/10	2002/05	80629	99%	7.2	686
Mahailluppallama	40	8 07	80 28	2000/09	2002/03	69216	92%	4.0	73

NOTES:
1) Anemometer heights (An Ht) are in meters above ground. Latitudes (Lat) are in deg/min N, longitudes (Lon) in deg/min E. Number of observations (NObs) is defined as the number of records. PCD refers to the percent of data recovery. Wind speeds (WS) are in m/s and wind power densities (WPD) are in W/m^2. Averaging all available data derived speed and power values in this table. Partial years will tend to bias the averages, if there are more data from windy months than from calmer months or vice versa.

5.3.1 Automated Data Processing (ADP) Data

The ADP data set contains upper-air observations from rawinsonde instruments and pilot balloons for approximately 1800 stations worldwide. Observation times can include 00, 06, 12, and 18 Coordinated Universal Time (UTC). Wind information is available from the surface, the mandatory pressure levels (1000 millibar [mb], 850 mb, 700 mb, and 500 mb), the significant pressure levels as determined by the vertical profiles of temperature and moisture, and specified geopotential heights above the surface. The significant pressure levels and geopotential heights are different for each upper-air observation. NREL's data set has more than 25 years of observations.

The ADP upper-air database consists of information obtained from surface-launched meteorological-instrument packages. These packages are launched via balloon once or twice daily, usually at 0000 UTC and 1200 UTC and are managed under WMO guidance and procedures.

The ADP database contains upper-air wind data for four locations in Sri Lanka and two in the Maldives, as shown in Tables 5.2 and 5.3. Data from Colombo and Hambantota in Sri Lanka and Male' and Gan in the Maldives, as well as some data from India, were used for this analysis.

Table 5.2 Upper-Air (Weather Balloon) Stations in Sri Lanka

ID	Name	Lat	Lon	Elev	NObs
434130	Mannar	8 58	79 55	3	3743
434180	Trincomalee/Chi AFB	8 34	81 15	70	6824
434660	Colombo	6 54	79 52	7	12460
434970	Hambantota	6 07	81 07	20	9068

Table 5.3 Upper-Air (Weather Balloon) Stations in the Maldives

ID	Name	Lat	Lon	Elev	NObs
435550	Male'	4 12	73 31	2	2523
435990	Gan	-0 40	73 09	2	1803

The ADP data yielded profiles of monthly and annual average wind speeds and frequency distributions of wind speed and wind direction for a number of pressure levels and height levels from the surface through 700 mb (approximately 3,000 m). Plots of the ADP data output for five stations in the region are included in Appendix D.

5.3.2 Computer Model-Derived Data Sets

5.3.2.1 Global Upper-Air Climatic Atlas (GUACA)

The GUACA data set contains computer-model-derived monthly means and standard deviations of climatic elements for 15 atmospheric levels (surface and 14 pressure levels) at grid points every 2.5° throughout the world. GUACA was developed using analyses produced at the European Centre for Medium Range Weather Forecasts. NREL's data, obtained from the NCDC, covers the period from 1980 to 1991. This data set is used to supplement the ADP information in areas where upper-air data are scarce. The levels of interest for this study include surface, 850 mb, 700 mb, and 500 mb.

The GUACA data were used to generate wind roses of the prevailing wind directions and to estimate the wind speeds at 850 mb and 700 mb for the analysis of the wind resource. Trends in wind speed and direction from across the GUACA grid helped to describe the large-scale wind patterns across the two countries.

5.3.2.2 Reanalysis Data

The U.S. National Centers for Environmental Prediction, in collaboration with NCAR, produced a reanalysis data set. This is a 40-year record of global analyses of atmospheric parameters. This project used a global weather prediction computer model to create worldwide data sets of wind, temperature, and other variables on a global 208-km resolution grid. Reanalysis incorporates all available rawinsonde and pilot balloon data, as well as observations from surface, ship, aircraft, satellites, and other data sources. Reanalysis data over Sri Lanka and the Maldives were produced for four times a day. Plots of Reanalysis output for two grid points in Sri Lanka are presented in Appendix D.

5.3.2.3 Mesoscale Model Data

TrueWind Solutions provided NREL with wind speed and wind power data for Sri Lanka on a 400-m by 400-m grid with data at levels from 30 m to 500 m above ground. Surface roughness and elevation data from its proprietary MesoMap system were also provided to NREL. This data set was used as an initial estimate for the distribution of the wind resource (power) throughout Sri Lanka.

5.4 Satellite Ocean Wind Data

Because both Sri Lanka and the Maldives are surrounded by ocean, measurements and estimates of ocean winds can greatly aid the wind resource assessment studies. The satellite SSMI data set contains estimates of 10-m ocean wind speeds. These data also provide an excellent overview of the ambient wind conditions in the ocean areas off the coasts of the two countries. Maps and graphs of ocean satellite data for both countries are presented in Appendix E.

6.0 Wind Resource Characteristics of Sri Lanka

6.1 Introduction

This section presents an overview of the wind mapping results and wind power density estimates for Sri Lanka. The classification scheme for wind power density used in the atlas is applicable for utility-scale applications.

6.2 Wind Power Classifications

Table 6.1 shows the wind power classifications for utility-scale applications in Sri Lanka. Wind resource areas of Class 4 and higher are considered suitable for utility-scale wind power development. Rural or off-grid applications require less wind resource for a project to be viable. For these types of applications, Class 2 and higher resources may be sufficient for viable wind power development.

Table 6.1. Wind Power Classification

Class	Resource Potential (Utility-Scale)	Wind Power Density (W/m^2) @ 50 m agl	Wind Speed [a] (m/s) @ 50 m agl
1	Poor	0 – 200	0.0 – 5.6
2	Marginal	200 – 300	5.6 – 6.4
3	Moderate	300 – 400	6.4 – 7.0
4	Good	400 – 500	7.0 – 7.5
5	Excellent	500 – 600	7.5 – 8.0
6	Excellent	600 – 800	8.0 – 8.8
7	Excellent	> 800	> 8.8

[a] Mean wind speed is estimated assuming a sea level elevation and a Weibull distribution of wind speeds with a shape factor (k) of 2.0. The actual mean wind speed may differ from these estimated values by as much as 20%, depending on the actual wind speed distribution (or Weibull k value) and elevation above sea level.

6.3 Approach

The mapping methodology used in this project was described in Section 4.0. The mesoscale model data from TrueWind Solutions were used as the initial estimate of the wind power in Sri Lanka. Adjustments to the initial power estimates in certain regions were made after NREL's evaluation of the available meteorological data. The data from the CEB was quite valuable in this regard. The major adjusted regions were selected coastal areas, the central highlands, the area southwest of Trincomalee, and northern Sri Lanka. Because no obvious high-quality measurement stations were available in northern Sri Lanka, adjustments to the initial power estimates for this region were based on the adjustments made to the west coast supplemented by information from ocean satellite and climatic data.

6.4 Wind Resource Distribution and Characteristics

6.4.1 Annual Wind Resource Distribution

Figures 6.1 to 6.3 show the wind resource maps of Sri Lanka. Figure 6.1 is the basic wind resource map, which shows the wind resource values, the provincial boundaries, and the major water bodies (lakes and lagoons). This figure clearly shows the wind resource values of specific areas without being obscured by other information. In addition to the wind resource, Figure 6.2 shows the major transmission lines and roads. This figure clearly relates the distribution of the wind resource to the major transmission lines and roads. Wind resource areas located near major transmission lines and roads are usually more suitable for potential utility-scale wind energy development than remote locations. Figure 6.3 shows the wind resource in combination with the hill-shaded relief. This figure relates the wind resource to major terrain features, such as mountains, hills, and valleys, in Sri Lanka. Very dark or bright areas on the hill-shaded relief map are typically areas of steeply sloped terrain. These steep areas are generally not suitable for wind energy development because of the turbulent wind conditions often associated with the steep slopes. (As previously noted in Section 4.3.3, the wind resource values are not calculated for steep areas with greater than a 20% slope.)

The good-to-excellent wind resource areas (Class 4 and higher) are concentrated in two major areas of Sri Lanka. The first is the western coastal region from the Kalpitiya Peninsula north to the Jaffna Peninsula. The highest levels of resource in this region are estimated to extend from the northern tip of the Kalpitya Peninsula to the Karativu Islands near Portugal Bay and through Mannar and Delft Islands. The second region is the central highlands in the country's, largely in the Central Province but also in parts of Sabaragamuwa and Uva Provinces. Much of the highlands region is over 1500 m in elevation, and the best sites are primarily those that are well exposed to the strong southwest monsoon winds. Wind power Classes 6 and 7 are depicted for the best exposed areas in this region. Other regions with notable areas of good wind resource include exposed terrain to the north and south of the central highlands, where the monsoon winds are accelerated. These regions include the extreme northern part of the Central Province, the southern part of the North Central Province, and the southern parts of Uva and Sabaragamuwa provinces. Finally, coastal areas in the southeastern part of the Southern Province and the southern tip at Dondra Head are estimated to have Class 4 resource.

Sri Lanka is influenced by two predominant wind flows, the southwest monsoon and the northeast monsoon. The stronger of the wind flows, the southwest monsoon, affects the country from May through September. The direction of the wind during this monsoon varies from the southwest to west depending on elevation, with the winds generally becoming more westerly with increasing elevation. The strong upper-air winds (greater than 10 m/s) during this season can extend from just a few hundred meters above sea level to more than 2000 m above sea level. Therefore, locations, such as the ridges in the central highlands that are fully exposed to these strong free-air winds can have Class 6 or Class 7 annual wind resource. The northeast monsoon lasts from December through February. The wind direction during this period is persistently from the northeast. Overall, the northeast monsoon free-air winds are weaker than the southwest monsoon with the peak winds around 7 to 8 m/s. The strongest free-air winds in this flow are only 600 m to 1000 m above sea level making the northeast monsoon a more shallow wind flow than the southwest monsoon. Vertical profiles of wind speed from the Reanalysis data set show the differences between the southwest and northeast monsoon in Appendix D. Because the peak free-air winds in the northeast monsoon are closer to the surface than the southwest monsoon, comparatively more of the momentum in the northeast monsoon can be mixed down to the near sea level elevations. This mixing of the northeast monsoon momentum toward the surface can lead exposed low-elevation locations, such as Hambantota, to have less disparity in the wind resource between the southwest and northeast monsoon seasons compared to the disparity at exposed stations in the central highlands. The months of March, April, October, and November are inter-monsoon periods. The winds during these periods are lighter than they are in the two monsoon periods, though episodic stronger winds associated with the monsoons can occur during these months.

The sea level regions with the highest wind resource in Sri Lanka can be found on the northwest coast from the Kalpitya Peninsula in the North Western Province north through the Jaffna District of the Northern Province. These areas receive most of their wind resource from the southwestern monsoon. The southwest monsoon flow accelerates across the Indian Ocean south of the Indian mainland and is quite strong (8-9 m/s at 10 m height) as it approaches the west-central coast of Sri Lanka. Part of that flow turns towards the northeast and heads through the strait between northern Sri Lanka and the coast. South of the higher resource area, the southwest monsoon winds are reduced due to less acceleration around the coast of India and large-scale terrain blocking by the central highlands. The northern part of Sri Lanka has better exposure to the northeast monsoon than the west coast. While the southwest monsoon provides most of the resource in northern Sri Lanka, the ocean satellite data indicate there is at least Class 3 wind resource available from the northeast monsoon. High quality measurement data was not available from northern Sri Lanka, but the climatic data indicate the seasonal contrast between the southwest and northeast monsoon is less pronounced in northern Sri Lanka compared to the west coast.

Another coastal region with good resource consists of selected areas along the Indian Ocean in southern Sri Lanka. Prominent among these areas are Dondra Head at the southern tip and the coastal strip from Hambantota to near the eastern border of the Southern Province. Both the southwest monsoon and the northeast monsoon accelerate around the southern end of Sri Lanka, and the coastal capes that extend into the ocean closest to the accelerated wind flow have the highest resource. However, the good resource does not extend more than a few kilometers inland from the coastline. The winds blow parallel to the coast, so the wind flow has an overland trajectory for areas inland from the coast. Surface roughness and stability weaken the low-level wind considerably for these areas. Consequently, there can be large gradients in the available wind resource along the south coast between the coastal capes and inland areas only a few kilometers away.

The central highlands have the most concentrated areas of excellent (Class 5 and higher) wind resource in Sri Lanka. Much of the region is over 1500 m in elevation, and sites exposed to the strong southwest monsoon have Class 6 and Class 7 resource. The disparity in the available wind resource between the southwest and northeast monsoon is much larger in the central highlands than for locations on the coast. For example, the measurements from the CEB station at Ambewela at an elevation of 1800 m (Appendix C) indicate that virtually all of the good to excellent wind resource at that site occurs from May through October. The winds from November through April are light and the northeast monsoon winds at Ambewela average only 4 m/s at 40 m above ground. We believe that light northeast winds would also prevail at most other high elevation wind energy candidate sites throughout Sri Lanka because these sites would be at elevations above the strongest free-air winds in the northeast monsoon. The exceptions to this would be sites either located at elevations near the strongest free-air wind speeds (600 m to 1000 m above sea level) or subject to acceleration of the northeast winds by local terrain.

6.4.2 Seasonal Wind Resource Distribution

The exact seasonal distribution of the wind resource for a particular site in Sri Lanka depends on elevation, its location, and its exposure to the monsoon flows. Throughout Sri Lanka, most places exposed to both monsoon flows will have a maximum resource during June, July, and August with some having a secondary maximum resource from December through February. The only exception to this rule is along the east coast of the Eastern Province from south of Batticaloa to just south of Trincomalee. In this region, the maximum resource may occur in December and January from the northeast monsoon rather than June and July, because the high terrain in the highlands blocks and diminishes the southwest monsoon. The most important issue in regards to the seasonal wind resource distribution is the comparative strengths of the southwest and northeast monsoons. Exposed locations along the southern coast, on the northern tip, and along the northeastern coast exhibit the most balance between the southwest monsoon and northeast monsoon resource.

The seasonal distribution of the wind resource for several areas in Sri Lanka can be seen in Figures 6.2 and 6.3. These figures show the normalized (annual average represented by 1.0) seasonal wind speed and power for typical exposed stations in three regions of Sri Lanka: the central highlands, the west coast and offshore islands, and the southeast coast. All three regions have the maximum resource from May through September during the southwest monsoon but have differences in the distribution of the resource between the southwest and northeast monsoon seasons. The central highlands sites receive well over the annual average power from June through September (2.5 to 2.8 times the average from June through August) but well under the annual average power the remaining months. During the northeast monsoon, the available power is only about one-fourth the annual average. The resource at the west coast and islands sites peaks in June with 2 times the annual average and slowly decreases throughout the rest of the southwest monsoon. During the northeast monsoon, the months of December and January have about 70% to 80% of the annual resource at the west coast sites. Along the southeast coast, there is a broader distribution of the resource during the southwest monsoon season than what is found along the west coast. Southeast coastal sites have about 1.5 times the annual average resource for the period of June through September. The peak resource month during the northeast monsoon is January with the monthly wind speed and power near the annual average.

Data from several CEB measurement towers (Appendix C) illustrates seasonal trends of the three regions in more detail. Along the southeast coast, the 20-m tower near the Hambantota Meteorological Station recorded 8 m/s winds from June through September (Classes 5 and 6) and 6.5 to 7.5 m/s winds (Classes 3 and 4) from December through January. The seasonal distribution of the wind resource along the west coast is shown clearly by the data from the New Narakkalliya station on the Kalpitya Peninsula. There, Class 6 resource is measured during June, July, and August and Class 5 resource is measured during May and September. In contrast, Class 1 resource prevails from November through April. Finally, at Ambewela, in the central highlands about 1800 m in elevation, the seasonal contrast in resource is the strongest. Ambewela averages around 9 m/s and higher at 40 m (Class 7) from June through September but average speeds from November through April are only around 4 m/s (Class 1).

Figure 6.4 presents plots of monthly average wind speeds and power densities based on satellite data for selected regions just off the coast of Sri Lanka. These plots show the general seasonal distribution for coastal and offshore islands for these selected regions. Appendix E contains additional plots of the ocean satellite wind data. As shown by the interannual plots of the ocean satellite data included in Appendix E, not all years have close to the long-term average wind resource. For example, the year 1997 was an abnormally low wind resource year in the Sri Lanka region. This shows that long-term ocean satellite wind data can be used to examine whether short-term data (such as one year) from measurement sites are truly representative of the long-term wind resource.

6.4.3 Diurnal Wind Speed Distribution

The diurnal wind speed distribution (or wind speed versus time of day) is influenced by site elevation, topography, and direct exposure to the monsoon flow. The distribution at the low wind resource sites in the interior lowlands of Sri Lanka typically features a maximum wind speed during the afternoon and a minimum near sunrise.

The diurnal pattern at the higher wind resource sites between the south and west coasts of Sri Lanka have notable differences caused by how much marine conditions influence the wind climate. The diurnal pattern at locations strongly influenced by marine conditions is basically flat with little wind speed variation day or night, while areas with less marine influence exhibit more of the afternoon maximum wind speed pattern. Along the south coast, the measurement tower (20-m with Class 4 resource) near the old Hambantota Meteorological Station (Appendix C) shows a maximum wind speed during the afternoon and a minimum speed near sunrise. The annual average amplitude of the diurnal wind speeds is considerable at 4 m/s (5 m/s at sunrise to 9 m/s in the afternoon). The diurnal amplitude is around 3 m/s during the monsoon seasons and is larger during the inter-monsoon periods. The large diurnal amplitude at Hambantota demonstrates the large influence of the land mass compared to the ocean influence. The fact that the winds are generally parallel to the coast and not onshore probably accounts for the large influence of the land for high resource areas along this section of the south coast.

The 40-m tower at Narakkalliya (New Narakkalliya in Appendix C) on the west coast shows a much different diurnal pattern than the Hambantota tower. Overall, the annual average diurnal pattern is quite flat with a maximum resource in the afternoon and a minimum in mid-morning. The amplitude is only around 1 m/s. However, the annual average diurnal pattern is a combination of two seasonal diurnal patterns that are much different in character. The northeast monsoon from November through January has a maximum wind speed in the afternoon and a minimum speed near sunrise. The amplitude is about 2-3 m/s. In contrast, the southwest monsoon from May through September features a maximum wind speed that occurs around 2000 Local Standard Time (LST) and continues at about the same level until 0400 LST. The wind speed decreases and reaches its lowest speed around 1000 LST. The amplitude is also quite small, only about 1 m/s throughout the day. The low amplitude of the annual wind speed indicates that the marine influence is significant at this location and stronger during the southwest monsoon than the northeast monsoon.

Unfortunately, high-quality wind measurement data were not available from locations along the northern and northeastern coasts. It seems likely that locations along these coasts will have a flat diurnal profile with maximum resource from late afternoon through the early nighttime hours. Measurement data from a 20-m tower at Rameswaram, India (Mani, 1994), near Mannar Island indicates a 2 m/s amplitude with the highest wind speed occurring around 1900 LST and the lowest speed around 0800 to 0900 LST. Exposed areas along the northern coast that may be more strongly influenced by marine conditions will have an evening to nighttime wind speed maximum. Sites along the northeast coast may be more influenced by the land processes and are likely to have an afternoon maximum.

Exposed ridge crest locations frequently have nighttime maximums of wind speed from about 2200 LST to 0400 LST and a minimum near noon, similar to what is found for a marine diurnal pattern. The pattern in the central highlands is more complicated because of the very strong southwest monsoon flow for six months of the year (May through October) and the weak wind flow the remaining months of the year. The 40-m tower at Ambewela (Appendix C) shows a flat diurnal pattern with the average annual amplitude of about 1 m/s. There is a slight speed maximum near 1000 LST and a speed minimum near 2000 LST. However, in terms of wind power, the maximum power is from midnight to 0200 LST, and the minimum power occurs around 1400 LST. The weak wind period has the most influence on the wind speed pattern, but the southwest monsoon has the most influence on the wind power pattern. This "out of phase" pattern between the wind speed and wind power is also exhibited at other highlands measurement sites such as Ratninda and Hare Park (Appendix C).

6.4.4 Wind Direction Frequency Distribution

The prevailing wind directions throughout Sri Lanka are directly related to the two monsoon flows. The prevailing directions during the southwest monsoon vary from southwesterly along the western and northern coast to just south of due westerly along the south coast and in the central highlands. The directions from the northeast monsoon are generally from the northeast throughout Sri Lanka, though at some locations along the southern coast and in the highlands, the prevailing wind direction is more east-northeast. The monsoon flows are remarkably persistent with exposed locations showing little or no variation in wind direction during the monsoon periods. The transition months of March, April, October, and November generally feature winds from both the west and northeast.

6.4.5 Confirmation of Wind Resource Estimates

We compared the wind resource estimates on the maps to actual measurements at 14 locations where the CEB had recently collected data on towers that ranged from 20-m to 40-m high. We chose these specific 14 locations because the data collected at these sites appeared to be of sufficiently high quality to allow a reasonable comparison between the mapped and measured values. However, at most sites, precise locations and/or station exposures were not available. Also, many sites had only about one year of measurement data, which is not sufficient to resolve questions of year-to-year variability. These factors made the conclusions of the study somewhat tenuous but still useful. The results of this study are summarized in Table 6.2.

The estimated wind resource on the map was within one power class or about 20% of the annual measured wind power at 10 of the 14 locations. Local surface roughness around the Puttalam station, not in the original land cover data, is the likely cause of the low wind (Class 1) measured at the site. The Hare Park station, though located in a mountainous area, is located in a local depression and not fully exposed to the prevailing winds. Local depressions are too small to be accurately resolved in the modeling process. Consequently, the map estimates may be significantly higher than the measured values. We believe that locations fully exposed to the prevailing winds in the highlands such as Ambewela accurately reflect the available resource.

Ratinda has the largest disagreement between the estimated and measured value. It is probable that the station site is not exposed to the southwest monsoon as is the case of Hare Park, but we do not have any specific knowledge to support or refute this. We also do not have specific information about the exposure at Tanamalwilla, so it is not clear whether local conditions affect the measured resource or if the map over estimated the resource at this site.

Table 6.2. Wind Resource Comparison

Station Name	Wind Power Class	
	Measured	Map
Hambantota Met	4	4
Hambantota Wv Trap	3+	4
Mirrijjawila	1	2
Pattiyapola	1+	1
Bundala	3	3
Tanamalwilla	1+	3-
Sevanagala	2	2
Ambewela	6	6
Hare Park	2	5
Ratinda	1	7
Narakkalliya New	4	4
Puttalam	1	3
Mahailluppallama	1	1+
Karathivu	3	3

In summary, we believe that the annual wind power estimates shown on the map are within 20% of the measured values at over 80% of the sites used in this study. This degree of accuracy is comparable to other mapping projects and atlases that NREL has done, so we are confident the maps in this atlas reflect the distribution of the resource in Sri Lanka.

6.5 Regional Summaries of Wind Resource

Sri Lanka is divided into two regions for this atlas. The northern Sri Lanka region extends from the northern tip to about 8^o N Lat. The southern Sri Lanka region covers the area from 8^o south to the southern end of the country. There is some overlap between the two regional maps.

6.5.1 Northern Sri Lanka

Northern Sri Lanka primarily consists of low elevation areas. There is a series of hills in the central part of the region with the higher elevation hills between Anuradhapura and Trincomalee. Along the western coast, there are a series of spits and islands. The more prominent of these features from south to north are: the Kalpitiya Peninsula, Mannar Island, Delft Island, Punkudutivu Island, Karativu Island, and Mandativu Island. The northern tip of Sri Lanka contains the Jaffna Peninsula. Northern Sri Lanka also contains some large lagoons and bays. These include the Puttalam Lagoon, Jaffna Lagoon, and Koddiyar Bay near Trincomalee. Figures 6.5 through 6.7 show the political features, elevation features, and potential wind resource of this region.

The most concentrated areas of good-to-excellent resource in this region are located along the western and northern coasts. The areas estimated to have the best resource include the northern part of the Kalpitiya Peninsula and the Puttalam Lagoon, Mannar Island, Delft Island, and parts of the islands just west of the Jaffna Peninsula. The Jaffna Peninsula has moderate-to-good resource throughout the region with the better resources located on the lagoons and adjacent land areas and the land areas on the coast. Scattered areas along the west coast, from the southern part of the Kalpitiya Peninsula north to the Jaffna Peninsula, are also estimated to have good resource. Inland there are scattered areas of good resource in the North Central Province, mostly on some hilltops southwest of Trincomalee.

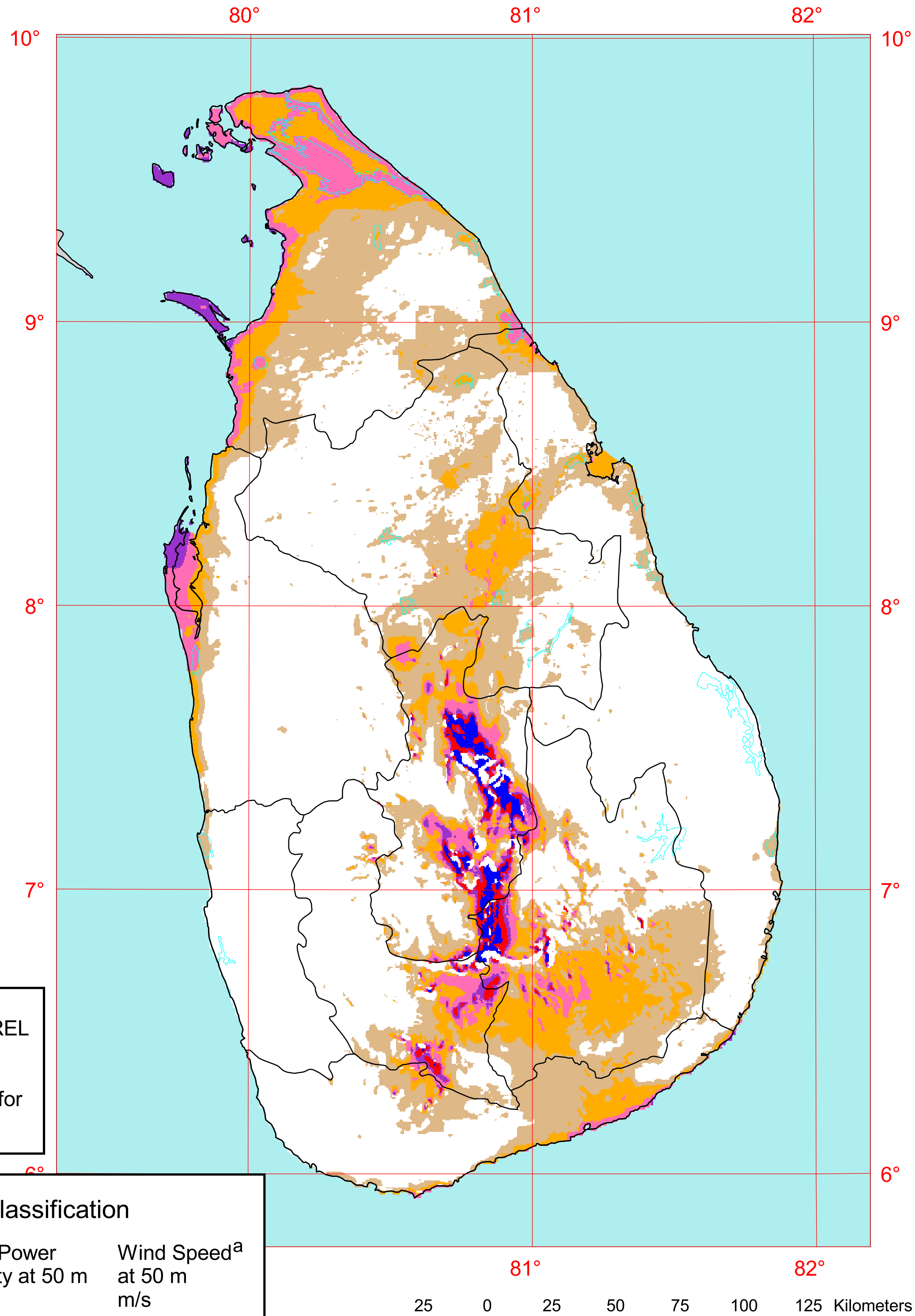
6.5.2 Southern Sri Lanka

The central highlands dominate the central two-thirds of southern Sri Lanka. Elevations can reach 2500 m in the highlands with significant areas over 1500 m. A southern spur of the highlands comes within 30 km of the southwest coast near Galle. There are isolated hills and small mountains between the southern and southeastern coasts and the highlands. West of the highlands is a plain that becomes broader north of Colombo. Figures 6.8 through 6.10 show the political features, elevation features, and potential wind resource of this region.

The central highlands are estimated to have the highest annual average wind resource in Sri Lanka. Excellent (Class 5 and higher) resource is found at locations exposed to the southwest monsoon. At the higher elevations (greater than 1500 m), virtually all of the available wind resource is due to the southwest monsoon. The main part of the excellent wind resource area runs from the northern edge of the highlands, to the high country north of Nuwara Eliya, south to west of Beragala. The southwestern spur of the highlands in the extreme southern part of the Province of Sabaragamuwa and the northern border of the Southern Province also has areas of excellent resource. Areas where the slope of the land is greater than 20%, especially near the World's End escarpment and in the Knuckles Range in the Central Province, have been given a "poor" resource value because of the turbulence associated with these land forms and the difficulty with developing wind energy projects on these extreme slopes.

There are good wind resource areas on the south coast from Hambantota east towards Palatupana. The good resource areas do not extend far inland because of the stability and surface roughness associated with the landmass. Other scattered coastal areas of good resource are found in the southern part of the Eastern Province and in the Southern Province near Dondra. There are good resource areas along the coast just south of the Kalpitya Peninsula and on the Mundal Lagoon.

Sri Lanka Wind Resource Map



This map was produced by NREL with technical assistance from TrueWind Solutions and with funding from the U.S. Agency for International Development.

Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m²	Wind Speed[a] at 50 m m/s
1	Poor	0 - 200	0 - 5.6
2	Marginal	200 - 300	5.6 - 6.4
3	Moderate	300 - 400	6.4 - 7.0
4	Good	400 - 500	7.0 - 7.5
5	Excellent	500 - 600	7.5 - 8.0
6		600 - 800	8.0 - 8.8
7		> 800	> 8.8

[a] Wind speeds are based on a Weibull k value of 2.0

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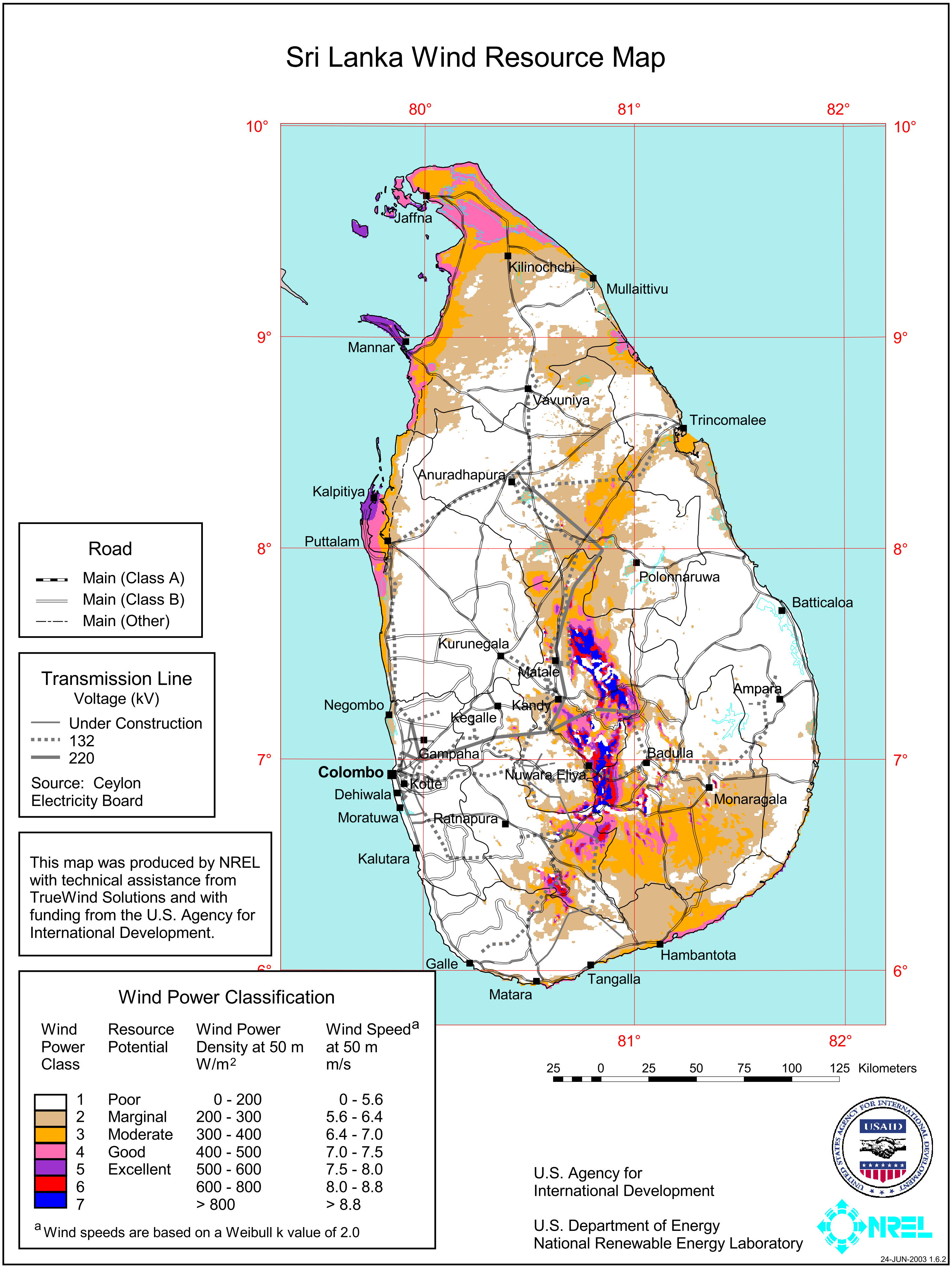
02-JUN-2003 1.6.1

Figure 6-1


Sri Lanka Wind Resource Map
80°
81°
82°
10°
9°
8°
7°
6°
Jaffna
Kilinochchi
Mullaittivu
Mannar
Vavuniya
Trincomalee
Anuradhapura
Kalpitiya
Puttalam
Polonnaruwa
Batticaloa
Kurunegala
Matale
Ampara
Negombo
Kandy
Kegalle
Gampaha
Badulla
Colombo
Kotte
Nuwara Eliya
Dehiwala
Monaragala
Moratuwa
Ratnapura
Kalutara
Hambantota
Galle
Tangalla
Matara
Road
Main (Class A)
Main (Class B)
Main (Other)
Transmission Line
Voltage (kV)
Under Construction
132
220
Source: Ceylon Electricity Board
This map was produced by NREL with technical assistance from TrueWind Solutions and with funding from the U.S. Agency for International Development.
Wind Power Classification
Wind Power Class
Resource Potential
Wind Power Density at 50 m W/m2
Wind Speed[a] at 50 m m/s
1 Poor 0 - 200 0 - 5.6
2 Marginal 200 - 300 5.6 - 6.4
3 Moderate 300 - 400 6.4 - 7.0
4 Good 400 - 500 7.0 - 7.5
5 Excellent 500 - 600 7.5 - 8.0
6 600 - 800 8.0 - 8.8
7 > 800 > 8.8
[a] Wind speeds are based on a Weibull k value of 2.0
25 0 25 50 75 100 125 Kilometers
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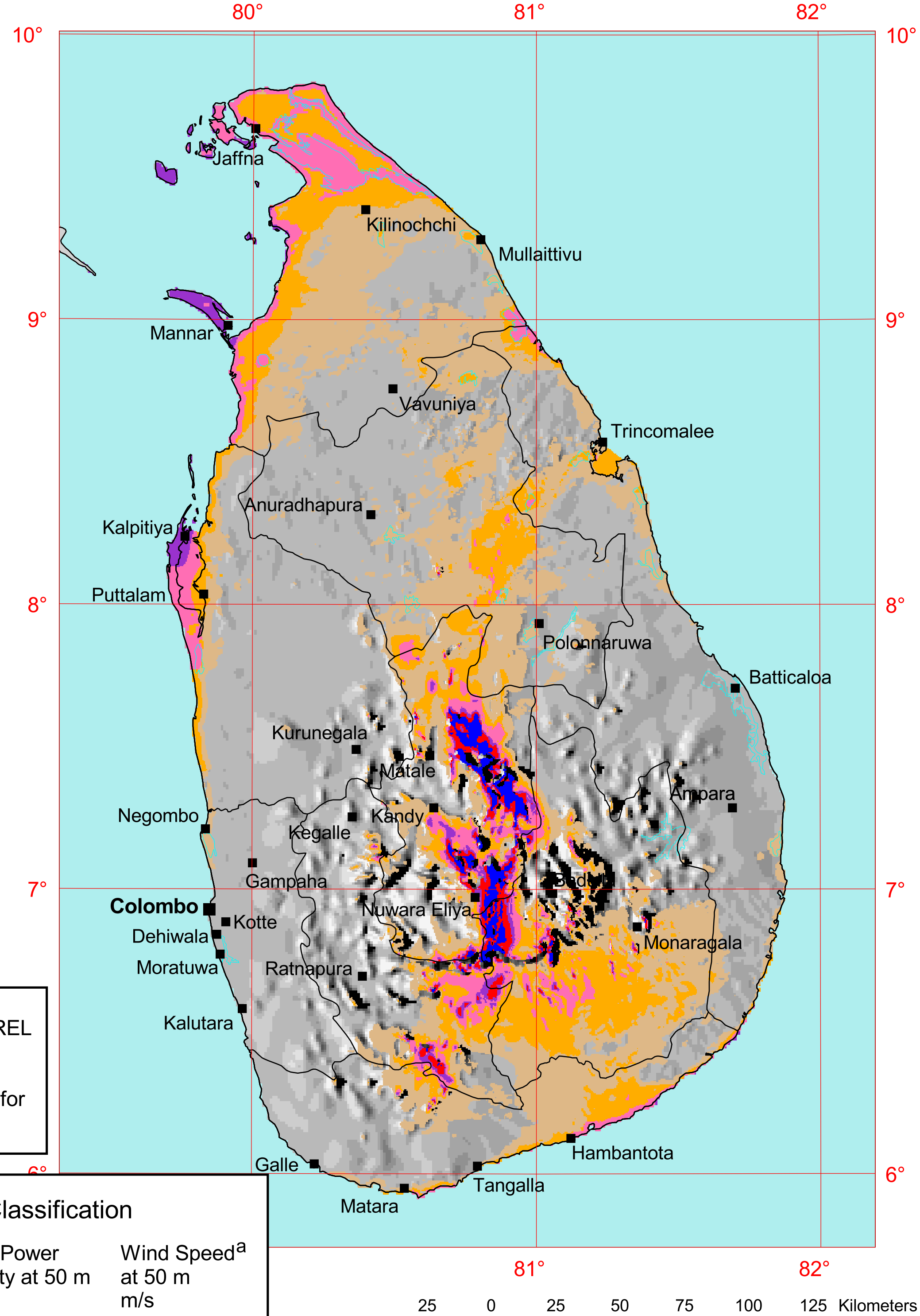
National Renewable Energy Laboratory
24-JUN-2003 1.6.2

Figure 6-2

Sri Lanka Wind Resource Map



This map was produced by NREL with technical assistance from TrueWind Solutions and with funding from the U.S. Agency for International Development.

Wind Power Classification

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4	Good	400 - 500	7.0 - 7.5
5	Excellent	500 - 600	7.5 - 8.0
6		600 - 800	8.0 - 8.8
7		> 800	> 8.8

[a] Wind speeds are based on a Weibull k value of 2.0

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Figure 6-3

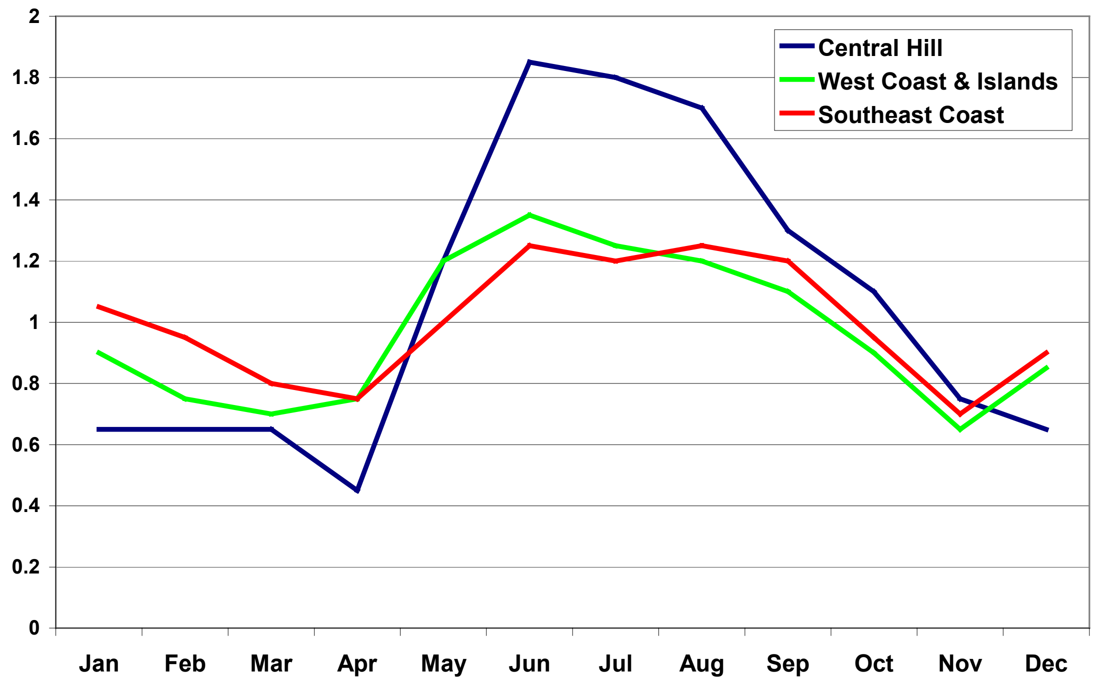


Figure 6.4 Sri Lanka – Monthly Normalized Wind Speed by Month.

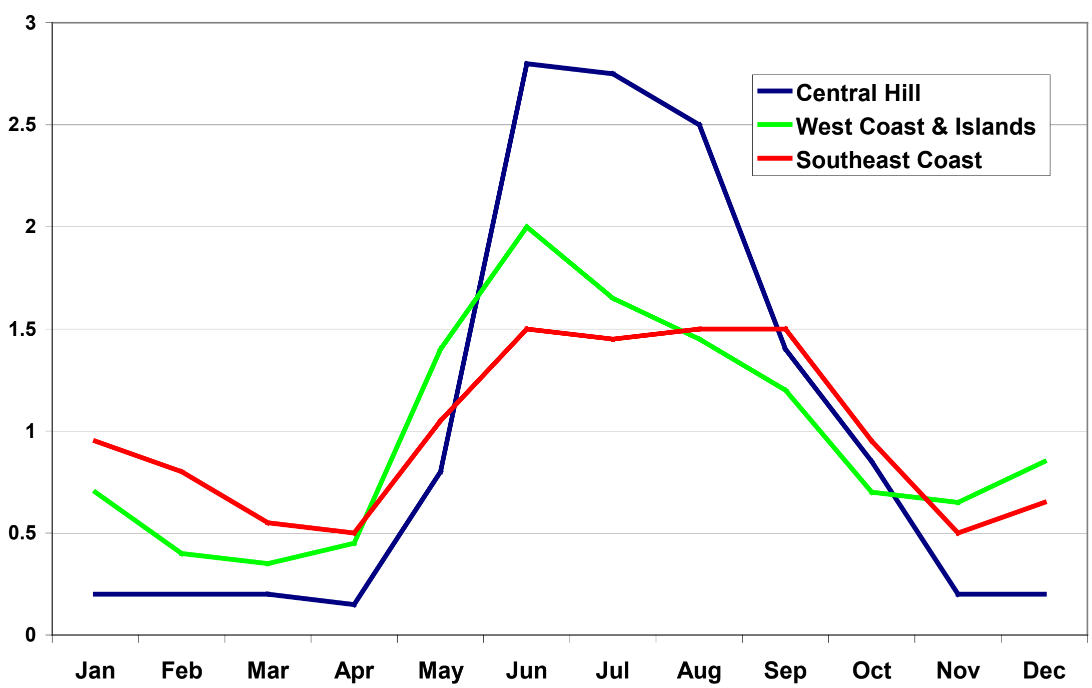


Figure 6.5 Sri Lanka – Monthly Normalized Wind Power by Month.

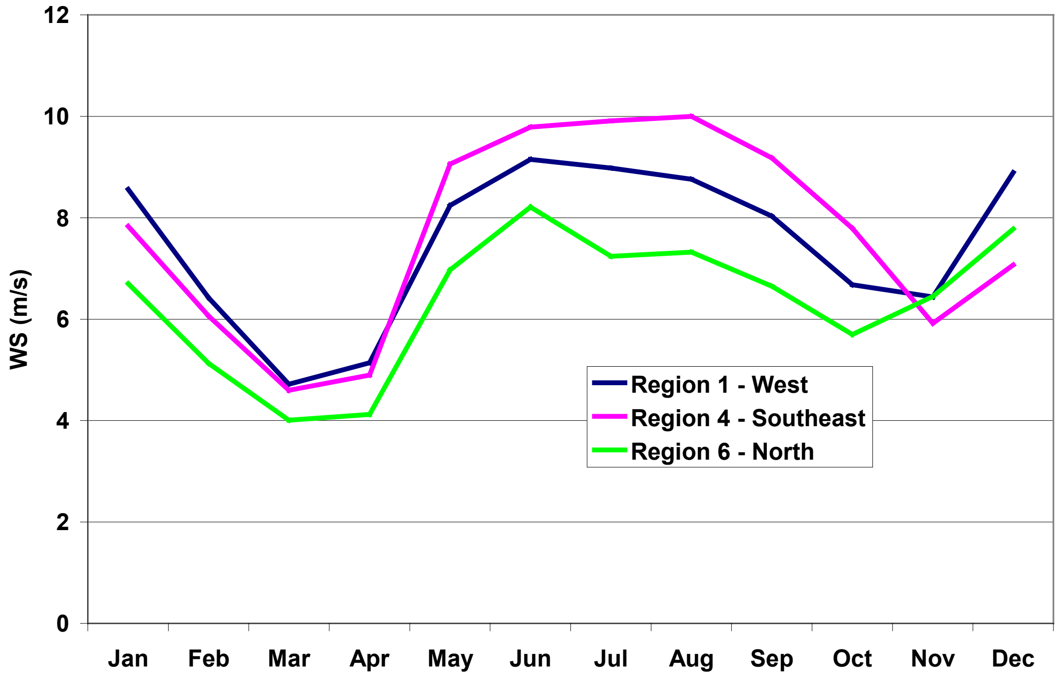


Figure 6.6 Sri Lanka – Ocean Satellite Monthly Average Wind Speeds and Power Densities.

Northern Sri Lanka - Political Base Map

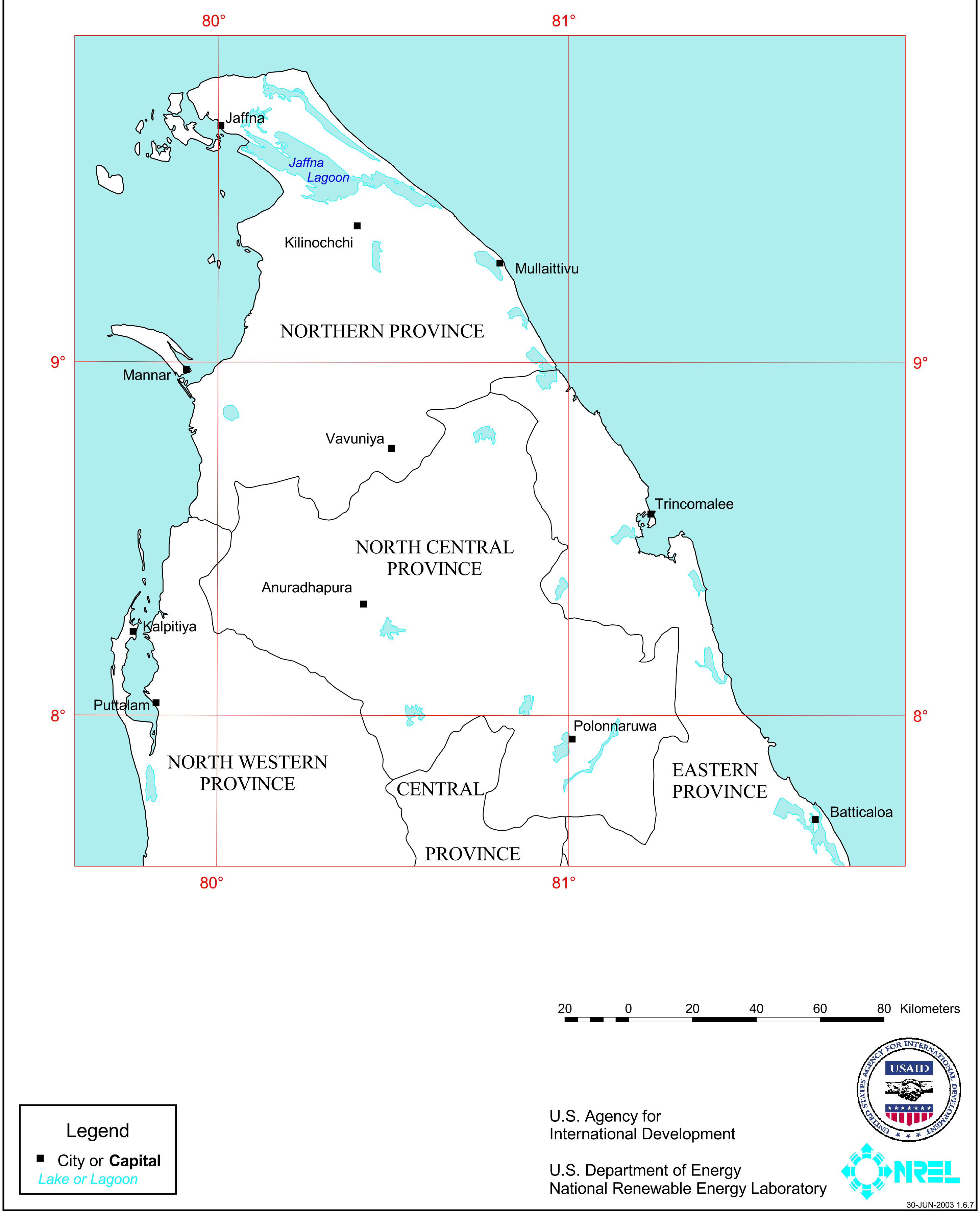


Figure 6-7

Northern Sri Lanka - Elevation Map

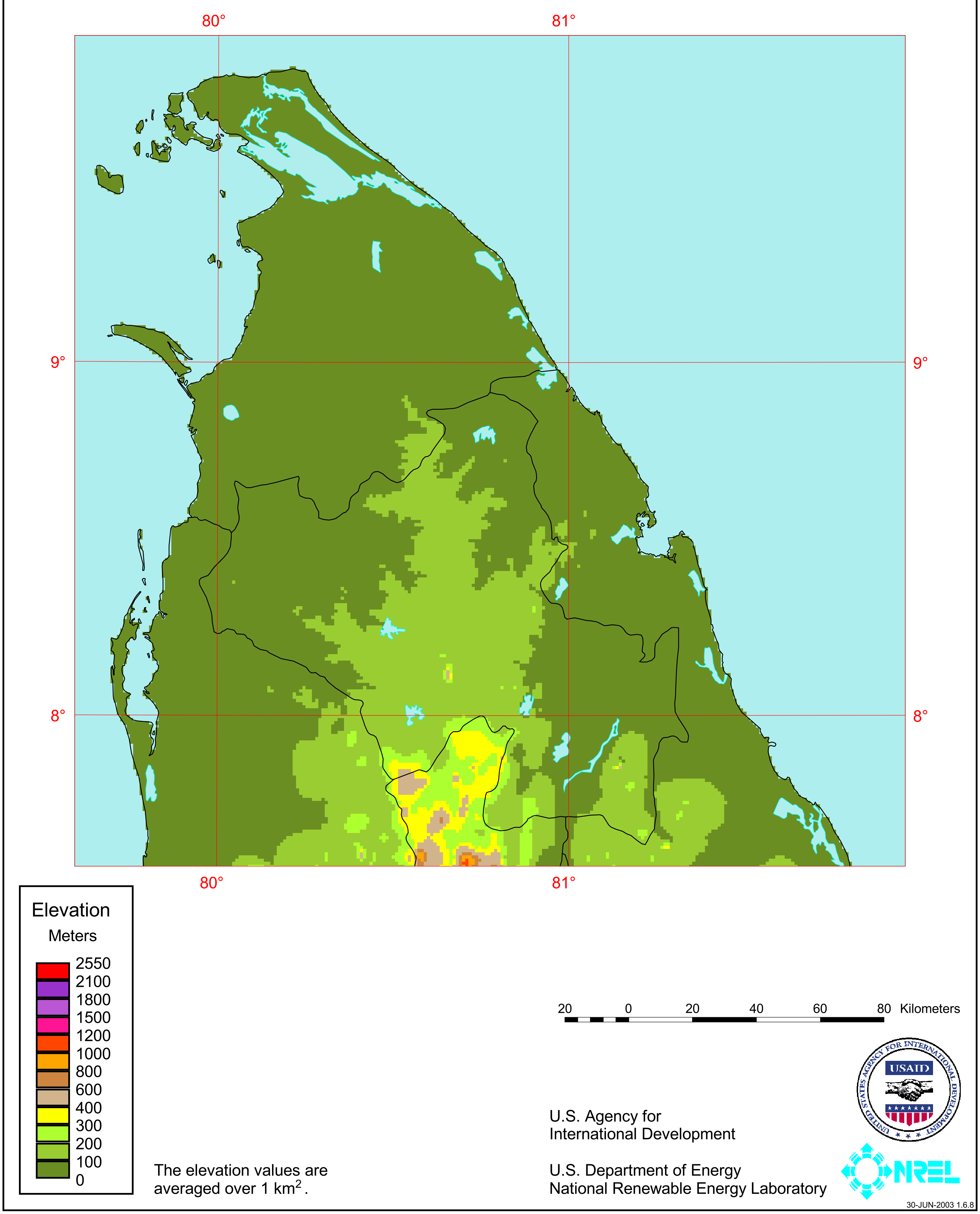
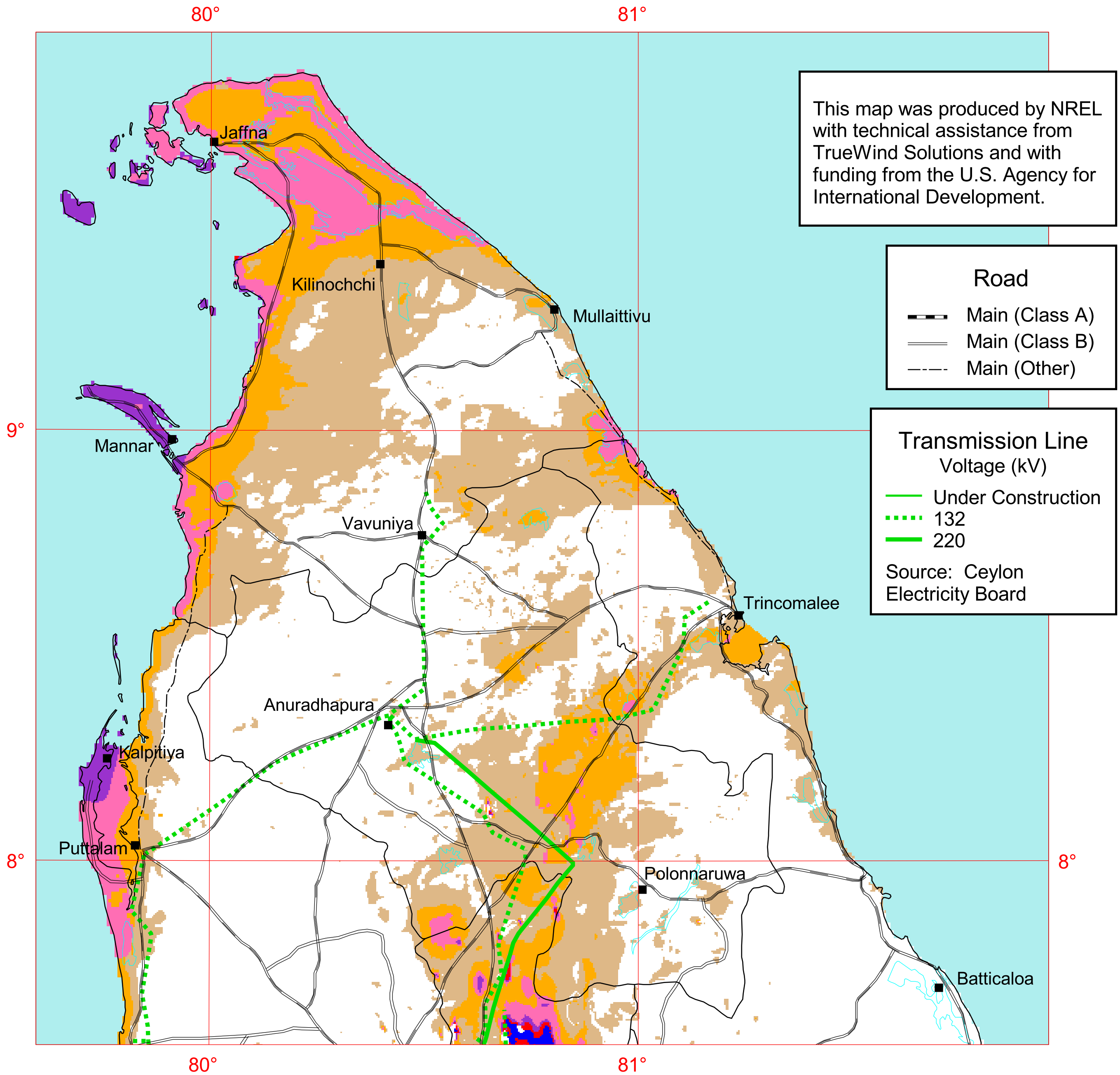


Figure 6-8

Northern Sri Lanka Wind Resource Map



Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m2	Wind Speed[a] at 50 m m/s
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5	Excellent	500 - 600	7.5 - 8.0
6		600 - 800	8.0 - 8.8
7		> 800	> 8.8

[a] Wind speeds are based on a Weibull k value of 2.0

20 0 20 40 60 80 Kilometers

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Figure 6-9

Southern Sri Lanka - Political Base Map

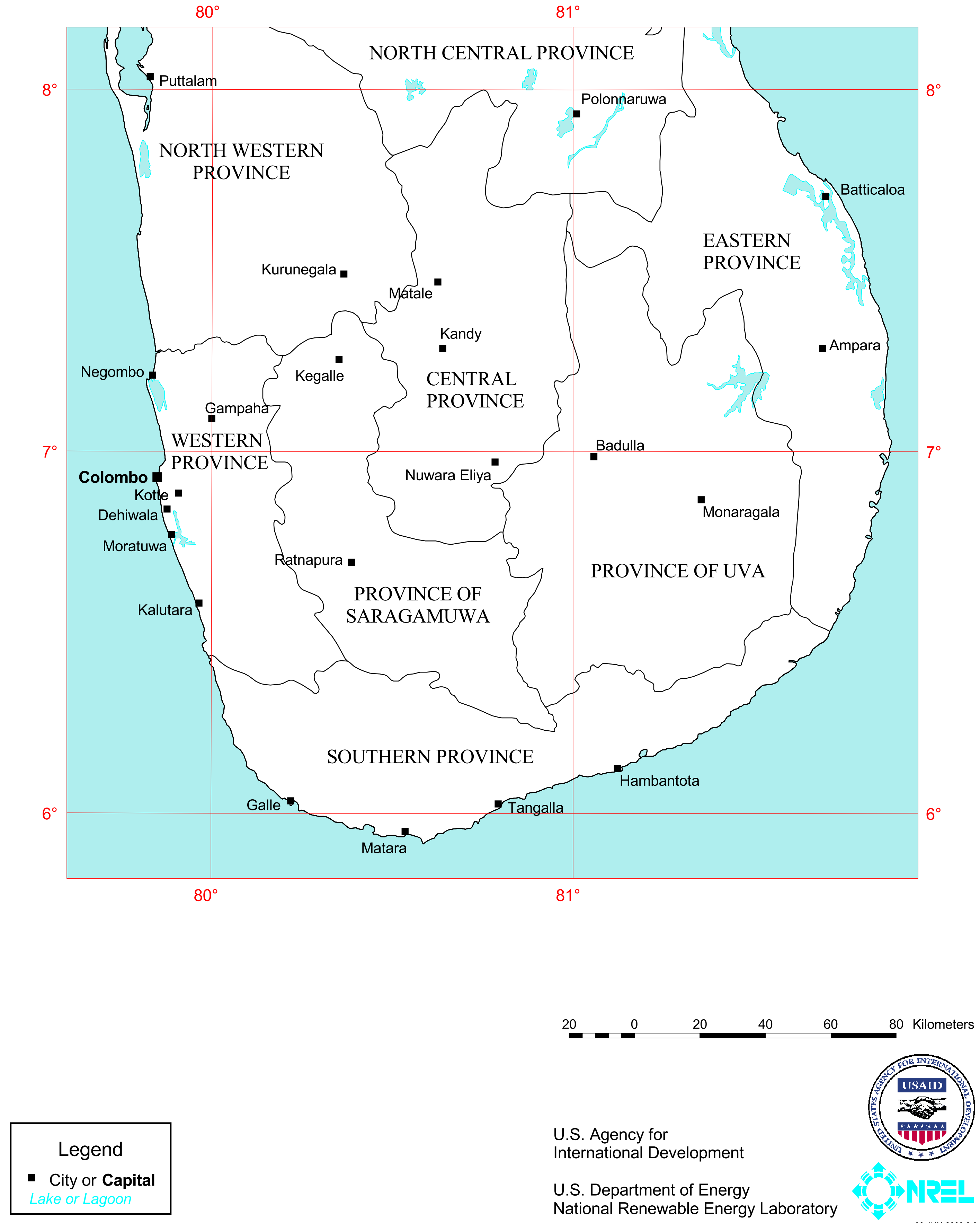
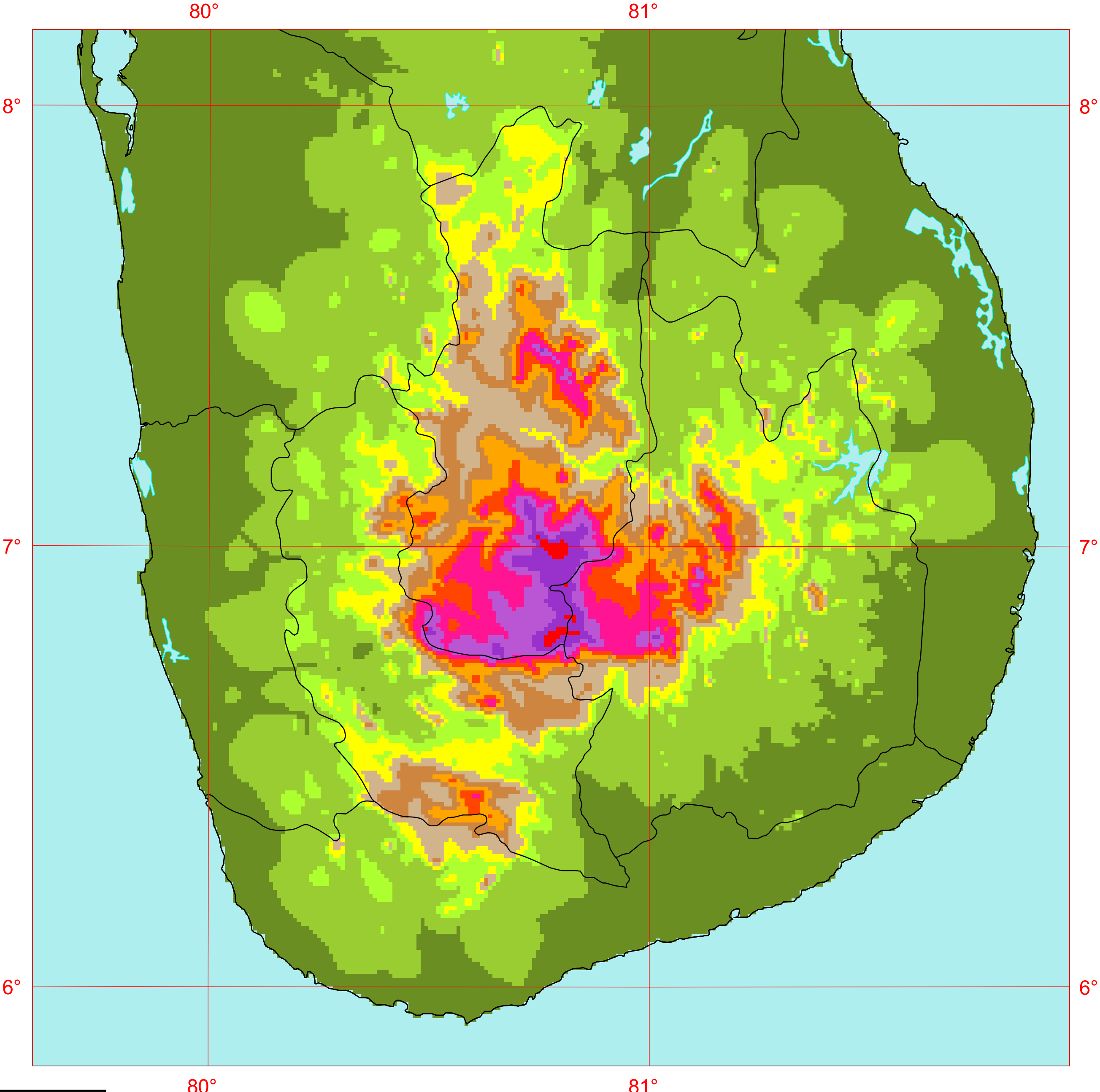
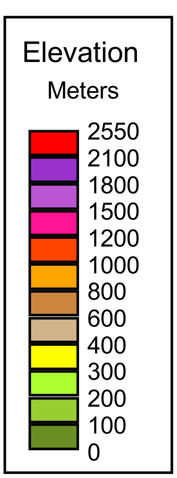


Figure 6-10

Southern Sri Lanka - Elevation Map





The elevation values are averaged over 1 km^2.

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Figure 6-11

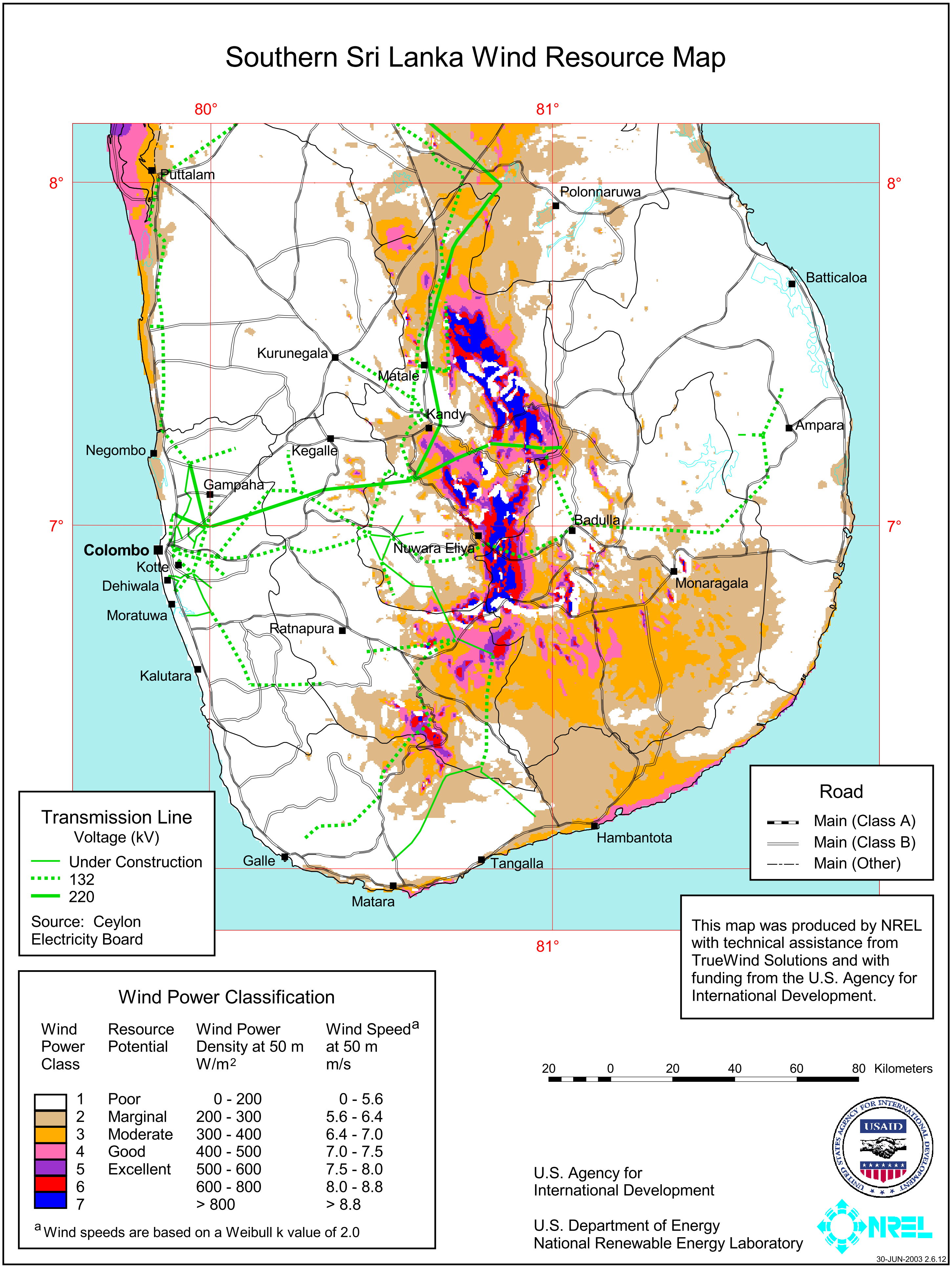

Southern Sri Lanka Wind Resource Map
80°
81°
8°
7°
Puttalam
Polonnaruwa
Batticaloa
Kurunegala
Matale
Kandy
Ampara
Negombo
Kegalle
Gampaha
Badulla
Colombo
Nuwara Eliya
Kotte
Dehiwala
Monaragala
Moratuwa
Ratnapura
Kalutara
Hambantota
Galle
Tangalla
Matara
Transmission Line
Voltage (kV)
Under Construction
132
220
Source: Ceylon Electricity Board
Road
Main (Class A)
Main (Class B)
Main (Other)
This map was produced by NREL with technical assistance from TrueWind Solutions and with funding from the U.S. Agency for International Development.
Wind Power Classification
Wind Power Class
Resource Potential
Wind Power Density at 50 m W/m2
Wind Speed a at 50 m m/s
1 Poor 0 - 200 0 - 5.6
2 Marginal 200 - 300 5.6 - 6.4
3 Moderate 300 - 400 6.4 - 7.0
4 Good 400 - 500 7.0 - 7.5
5 Excellent 500 - 600 7.5 - 8.0
6 600 - 800 8.0 - 8.8
7 > 800 > 8.8
a Wind speeds are based on a Weibull k value of 2.0
20 0 20 40 60 80 Kilometers
U.S. Agency for International Development
U.S. Department of Energy
National Renewable Energy Laboratory
30-JUN-2003 2.6.12

Figure 6-12

7.0 Wind Electric Potential of Sri Lanka

7.1 Introduction

The wind resource classifications in Table 7.1 match those shown on the wind resource maps for Sri Lanka. The installed capacity in the table represents net wind electric potential reduced by environmental exclusions such as national parks and reserves and archaeological and cultural sites (Figure 7.1). The Urban Development Authority of Sri Lanka provided the datasets for environmental exclusions. These GIS datasets are currently in the development process, so some areas may not be accounted for in this analysis. The wind potential estimates are divided into the potential on the land areas and the potential for the significant lagoon areas near the coast. The methods for converting the wind resource to wind electric potential are those used regularly by NREL. The assumptions used for the wind potential calculations are listed at the bottom of Table 7.1.

Each color-coded square kilometer on the map has an assigned annual wind power density at the 50-m height expressed in units of W/m^2. NREL uses a simple formula to compute the potential installed capacity for grid cells with an annual wind power density of 400 W/m^2 and greater (good-to-excellent wind resource). If the wind power density of a grid cell was less than 400 W/m^2, then the potential installed capacity was set equal to zero. Another scenario presented in this section included only those grid cells with an annual average power density of 300 W/m^2 and greater (moderate-to-excellent wind resource).

7.2 Wind Electric Potential Estimates

We estimate that there is nearly 5000 km^2 of windy areas with good-to-excellent wind resource potential in Sri Lanka. About 4100 km^2 of the total windy area is on land. The proportion of the windy land and lagoon potential wind capacity in each wind power category is listed in Table 7.1. This windy land represents about 6% of the total land area (65,600 km^2) of Sri Lanka. Using a conservative assumption of 5 MW per km^2, this windy land could support more than 20,000 MW of potential installed capacity. The windy lagoon areas are estimated to encompass 700 km^2 with a potential installed capacity of 3500 MW. The combined potential for Sri Lanka is estimated to be more than 24,000 MW. Figure 7.2 shows there are 5 provinces with at least 1000 MW of wind potential. Additional studies are required to accurately assess the wind electric potential, considering factors such as the existing transmission grid and accessibility.

If additional areas with moderate wind resource potential (which could likely become feasible in the near future with further advancements in wind technology) are considered, the estimated total windy land and lagoon areas (as shown in Table 7.1) increases to more than 11,000 km^2, or about 15% of the total land area of Sri Lanka. This amount of windy area could support more than 51,000 MW (55,000 MW if lagoons are included) of installed capacity. Figure 7.3 shows there are 7 provinces with more than 2000 MW of wind potential.

Table 7.2 shows the proportion of windy land in each province with good-to-excellent resource and moderate-to-excellent resource.

Table 7.1 Sri Lanka – Wind Electric Potential

Good-to-Excellent Wind Resource at 50 m

Wind Resource Utility Scale	Wind Class	Wind Power at 50 m W/m^2	Wind Speed at 50 m m/s*	Land Area km^2	Lagoon Area km^2	Total Area km^2	Percent Windy Land	Total Capacity Installed MW
Good	4	400 - 500	7.0 – 7.5	2,341	664	3,005	3.6	15,000
Excellent	5	500 - 600	7.5 – 8.0	788	41	829	1.2	4,150
Excellent	6	600 - 800	8.0 – 8.8	517	0	517	0.8	2,600
Excellent	7	> 800	> 8.8	501	0	501	0.8	2,500
Total				4,147	705	4,852	6.4	24,250

Moderate-to-Excellent Wind Resource at 50 m

Wind Resource Utility Scale	Wind Class	Wind Power at 50 m W/m^2	Wind Speed at 50 m m/s*	Land Area km^2	Lagoon Area km^2	Total Area km^2	Percent Windy Land	Total Capacity Installed MW
Moderate	3	300 - 400	6.4 – 7.0	6,119	196	6,315	9.5	31,600
Good	4	400 - 500	7.0 – 7.5	2,341	664	3,005	3.6	15,000
Excellent	5	500 - 600	7.5 – 8.0	788	41	829	1.2	4,150
Excellent	6	600 - 800	8.0 – 8.8	517	0	517	0.8	2,600
Excellent	7	> 800	> 8.8	501	0	501	0.8	2,500
Total				10,266	901	11,167	15.9	55,850

*** Wind speeds are based on a sea level elevation and a Weibull k value of 2.0**

Assumptions
Installed capacity per km^2 = 5 MW
Total land area of Sri Lanka = 65,610 km^2
Percent windy land calculation does not include windy lagoon area.

Table 7.2 Wind Electric Potential (on land only) by Province

Province	Good-to-Excellent Potential MW	Moderate-to-Excellent Potential MW
Central	7,550	11,750
Eastern	150	1,350
North Central	300	4,100
North Western	1,100	2,050
Northern	4,950	13,450
Sabaragamuwa	2,200	4,100
Southern	650	2,900
Uva	3,850	11,650
Western	0	0

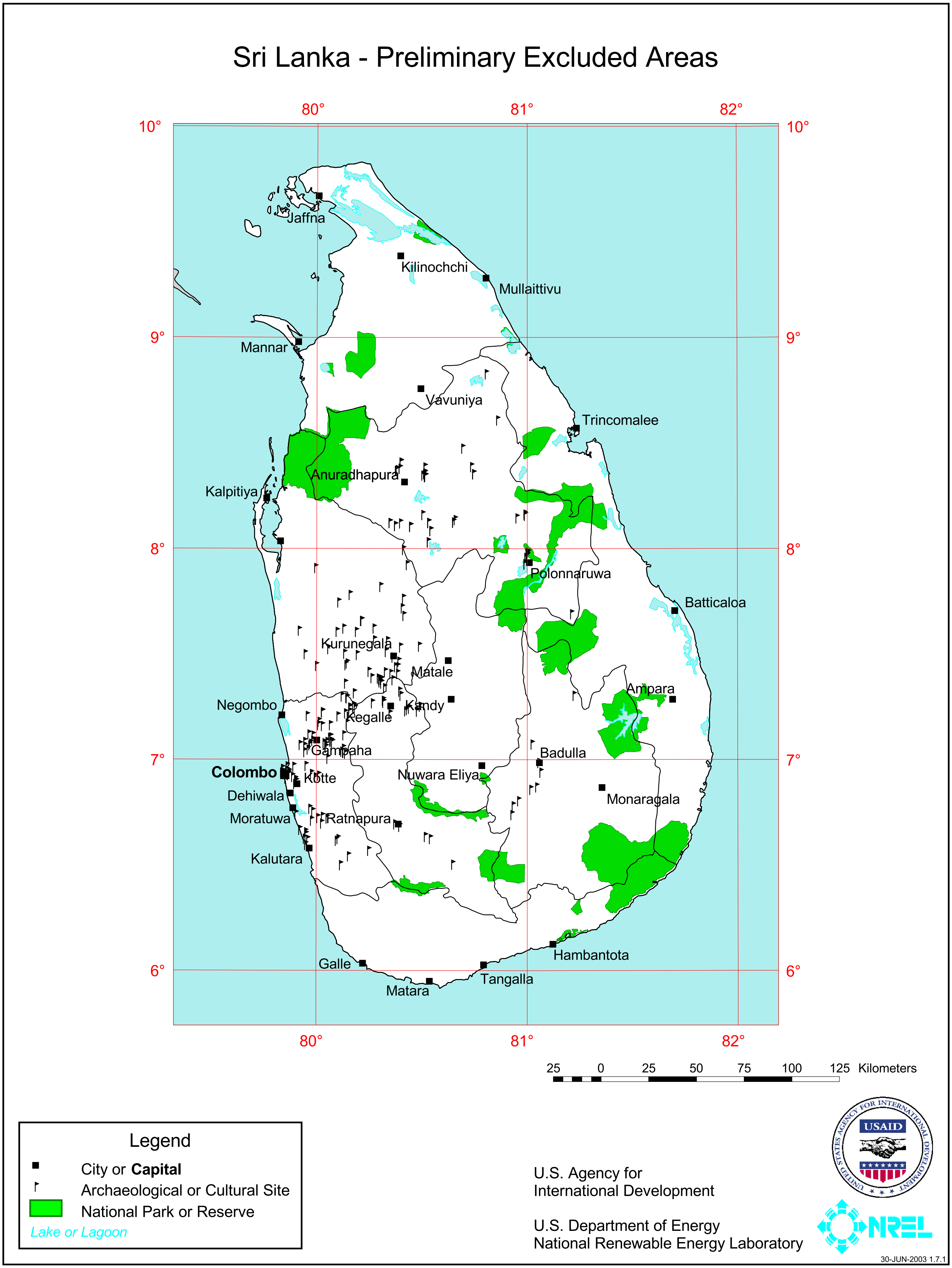
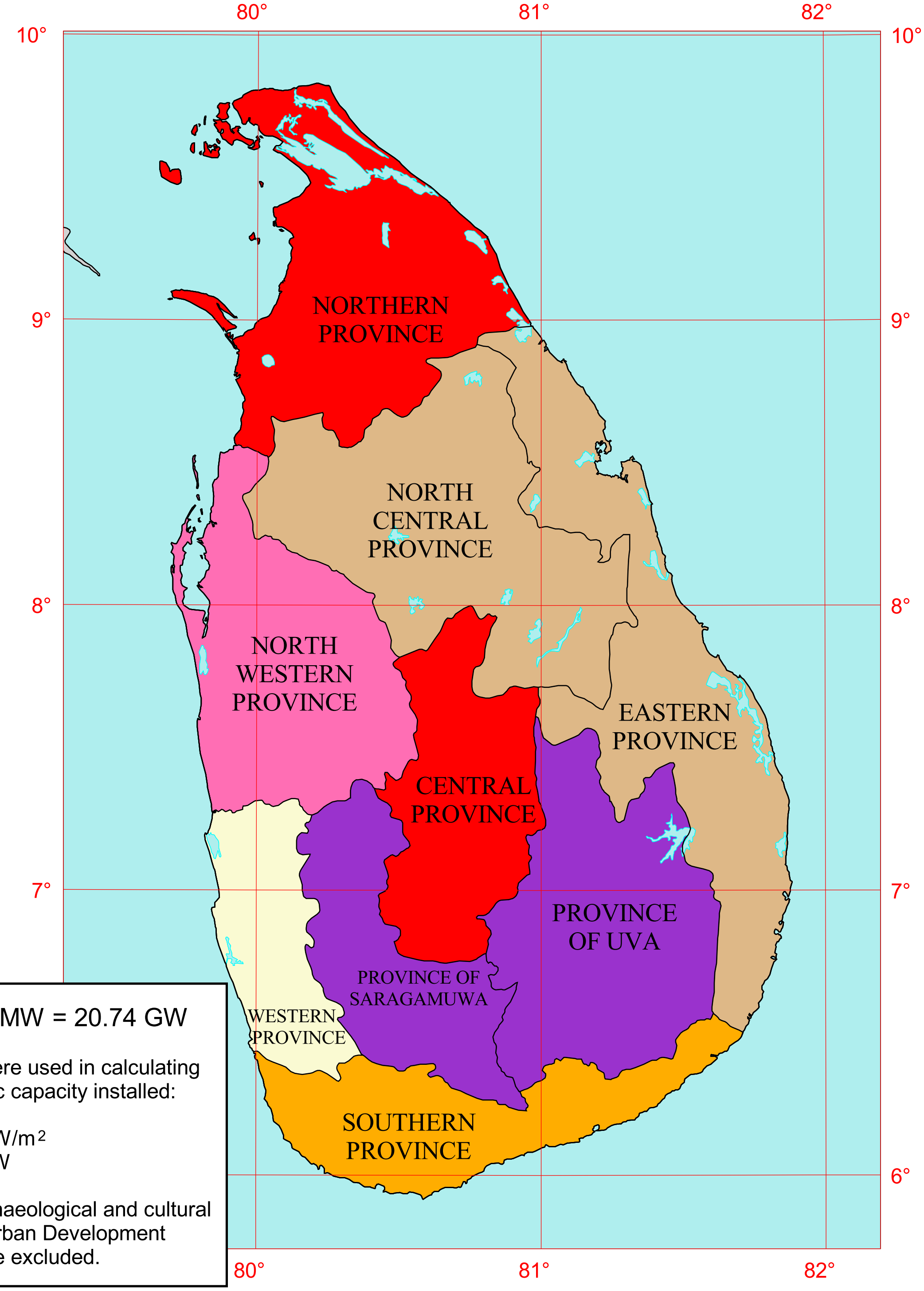

Sri Lanka - Preliminary Excluded Areas
80°
81°
82°
10°
9°
8°
7°
6°
Jaffna
Kilinochchi
Mullaittivu
Mannar
Vavuniya
Trincomalee
Anuradhapura
Kalpitiya
Polonnaruwa
Batticaloa
Kurunegala
Matale
Ampara
Negombo
Kandy
Kegalle
Gampaha
Badulla
Colombo
Kotte
Nuwara Eliya
Dehiwala
Monaragala
Moratuwa
Ratnapura
Kalutara
Hambantota
Galle
Tangalla
Matara
25 0 25 50 75 100 125 Kilometers
Legend
City or Capital
Archaeological or Cultural Site
National Park or Reserve
Lake or Lagoon
U.S. Agency for International Development
U.S. Department of Energy
National Renewable Energy Laboratory
30-JUN-2003 1.7.1

Figure 7-1

Sri Lanka - Wind Electric Potential

Good-to-Excellent Wind Resource (Utility Scale Classification)



Sri Lanka Total - 20,740 MW = 20.74 GW

The following assumptions were used in calculating the total potential wind electric capacity installed:

Miniumum wind power - 400 W/m²
Installed capcaity/km² - 5 MW
Windy land areas only
National parks, reserves, archaeological and cultural sites as provided by the Urban Development Authority of Sri Lanka were excluded.

Wind Electric Potential

Megawatts

Light yellow	0 - 100
Tan	100 - 500
Orange	500 - 1000
Pink	1000 - 2000
Purple	2000 - 4000
Red	4000 - 8000

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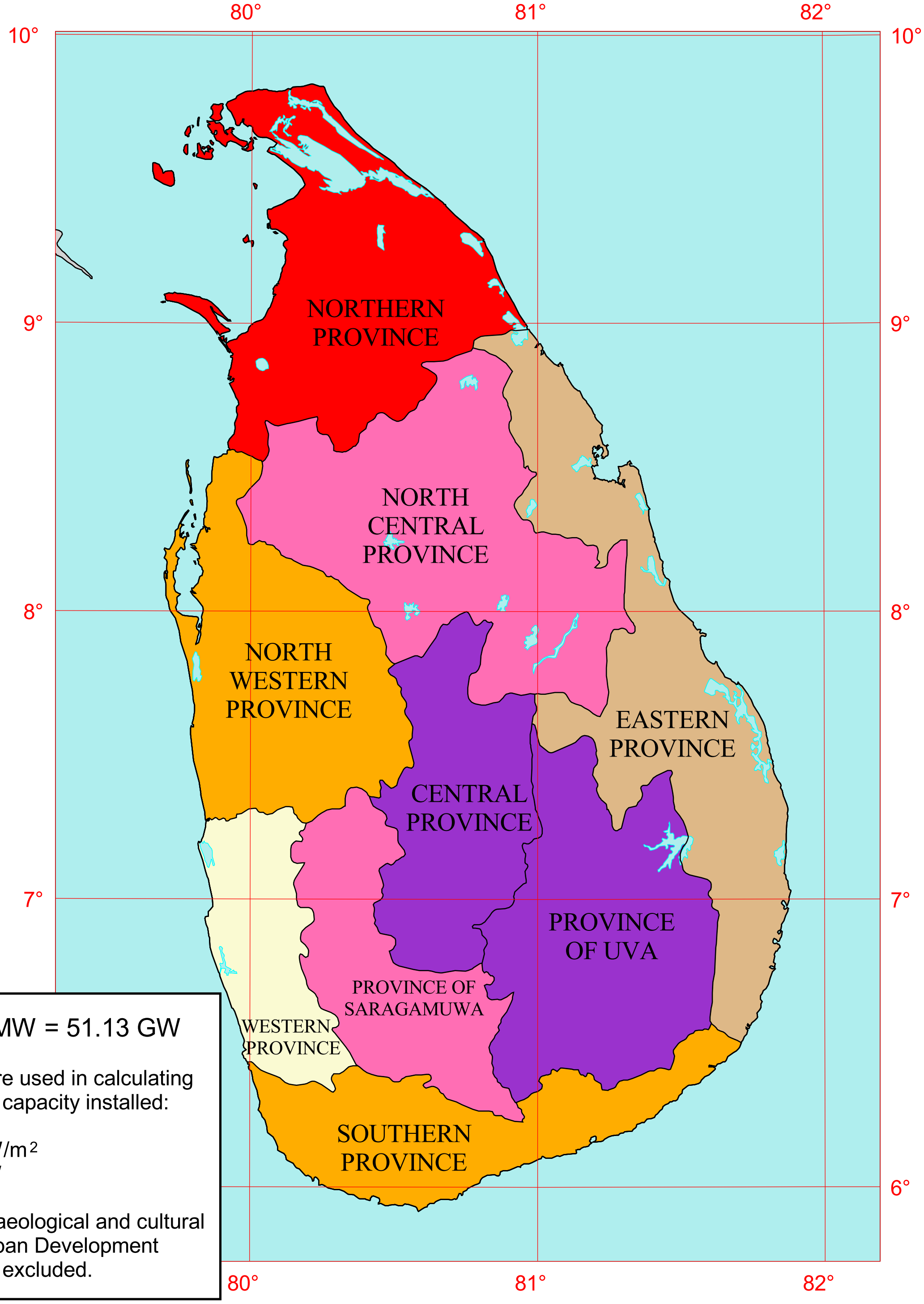
Figure 7-2

Sri Lanka - Wind Electric Potential

Moderate-to-Excellent Wind Resource (Utility Scale Classification)



Sri Lanka Total - 51,130 MW = 51.13 GW

The following assumptions were used in calculating the total potential wind electric capacity installed:

Miniumum wind power - 300 W/m^2
Installed capcaity/km^2 - 5 MW
Windy land areas only
National parks, reserves, archaeological and cultural sites as provided by the Urban Development Authority of Sri Lanka were excluded.

Wind Electric Potential
Megawatts

Megawatts
0 - 100
100 - 2000
2000 - 4000
4000 - 8000
8000 - 12000
12000 - 14000

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U.S. Department of Energy
National Renewable Energy Laboratory

30-JUN-2003 1.7.3

Figure 7-3

8.0 Wind Resource Characteristics of the Maldives

8.1 Introduction

This section discusses the approach, wind mapping results, and the wind power density estimates for the Maldives. The wind resource in exposed areas has relatively little variation in the Maldives, but it is important to emphasize the regions of the country where the better resource occurs. A simple wind classification with small wind power intervals scheme is used to represent the wind resource and is presented in Table 8.1. The Maldives is suited for village and resort wind turbine applications provided trees or other obstacles do not shelter the particular site. For this atlas, small-scale applications refer to 50 kW or less of installed capacity and large-scale applications have more than 50 kW. Economic and social factors in addition to the available resource will determine the feasibility of any wind energy project in the Maldives.

Table 8.1. Wind Power Classification

Resource Potential Large	Small	Wind Power Density (W/m^2) @ 50 m agl	Wind Speed [(a)] (m/s) @ 50 m agl
Fair	Moderate	225 – 250	5.8 – 6.0
Fair	Moderate	250 – 275	6.0 – 6.2
Fair	Moderate	275 – 300	6.2 – 6.4
Moderate	Good	300 – 325	6.4 – 6.5
Moderate	Good	325 – 350	6.5 – 6.7

[(a)] Mean wind speed is estimated assuming a sea level elevation and a Weibull distribution of wind speeds with a shape factor (k) of 2.0. The actual mean wind speed may differ from these estimated values by as much as 20 percent, depending on the actual wind speed distribution (or Weibull k value) and elevation above sea level.

8.2 Approach

The ocean module of NREL's wind mapping system was the basis of the wind power map of the Maldives. This module takes the ambient wind power at 50 m above the open ocean surface and adjusts it on the size of an affected island or coastal region. However, for the Maldives the individual atolls and islands are too small and the distance between the atolls too large to have a significant effect on the available resource. Therefore, the wind resource at 50 m for the atolls and islands are the same for the surrounding ocean areas. Surface roughness data for the Maldives islands were not available, but any trees or buildings will minimally affect the 50-m wind power values on the small islands. However, treed or other areas with obstructions will have considerably reduced resource at 20 m or 30 m compared to the 50 m values.

The open ocean values were based on two data sets. The most important data were the ocean satellite data that calculates the wind speed and power at 10 m above the surface. This information was converted to 50-m values based on a wind shear value commonly estimated for oceanic regions. The satellite data was supplemented by Reanalysis data that estimated the Weibull k values for the Maldives. Finally, the estimates of the open ocean values were referenced against surface data from the Male' airport and upper-air observations from Male' and Addu Atoll (Gan Island) to ensure the accuracy of these values.

8.3 Wind Resource Distribution and Characteristics

8.3.1 Annual Wind Resource Distribution

Figure 8.1 shows the wind resource map and the atoll names for the Maldives. The highest wind resource is found between 4.5^o N Lat and approximately 6.5^o N Lat. North Maalhusmadulu, South Maalhusmadulu, North Miladhunmadulu, South Miladhunmadulu, and Faadippolhu Atolls are estimated to have the best resource in the Maldives. This level of resource is estimated to be good for small-scale applications and moderate for large-scale applications. North and south of this area the wind resource is slightly lower but still considered good for small-scale and moderate for large-scale wind applications. These areas include the North Thiladhunmathi and South Thiladhunmathi Atolls at the northern end of the Maldives, and North Ari and Male' Atolls near 4^o N Lat. Male', the capital of the Maldives, is included in this wind resource area. The wind resource gradually decreases from Male' southwards with the lowest resource found on the atolls south of 1^o N Lat. However, the wind resource is still considered moderate for small-scale applications and favorable locations for wind energy projects may still be found as far south as Addu Atoll.

The Maldives is influenced by monsoon flows but the annual and seasonal patterns vary from north to south because strengths of the monsoon flows change with proximity to the equator. The strongest west monsoon occurs in the extreme north of the Maldives while the strongest northeast monsoon occurs in the north-central part of the country. The highest wind resource in the Maldives is located where the northeast monsoon is strongest. The west monsoon weakens in the southern part of the Maldives but still is of moderate strength down to Addu Atoll. The northeast monsoon decreases rapidly in strength south of Male' and is barely present at Addu Atoll. In fact, west winds predominate all year at Addu Atoll so it can be said that the monsoon flows stop somewhere north of that location. The weakening of the west and northeast monsoons results in a pronounced shift of the high wind resource months from the northern to the southern parts of the country, but the moderate west winds across the southern part of the Maldives keeps the variation in the overall resource in the Maldives relatively small.

The extreme northern part of the Maldives has a wind climate featuring a strong west monsoon from May through August and a moderate northeast monsoon from December through February. The ocean wind speeds during June, July, and August are strong with wind speeds from 6 m/s to 7.5 m/s at 10 m above the surface. The northeast monsoon is of moderate strength (4 m/s to 5 m/s) from December through February. Although the other months of the year can be considered inter-monsoon months, there is a prevailing northwest wind direction at this time. September and October have significantly stronger northwest winds than March and April.

The highest resource area in the Maldives that extends from just north of Male' to the North Miladhunmadulu Atoll experiences a stronger northeast monsoon from December through February than areas to its north and south. The stronger northeast monsoon has its origins in the accelerated flow around the southern tip of India. The west monsoon lasts from May through October with November being a transition month with characteristics of both monsoon flows. The northwest winds are not as evident as they are further north, with April, September, and October having the most northwest winds. March and April are the months with the lowest winds.

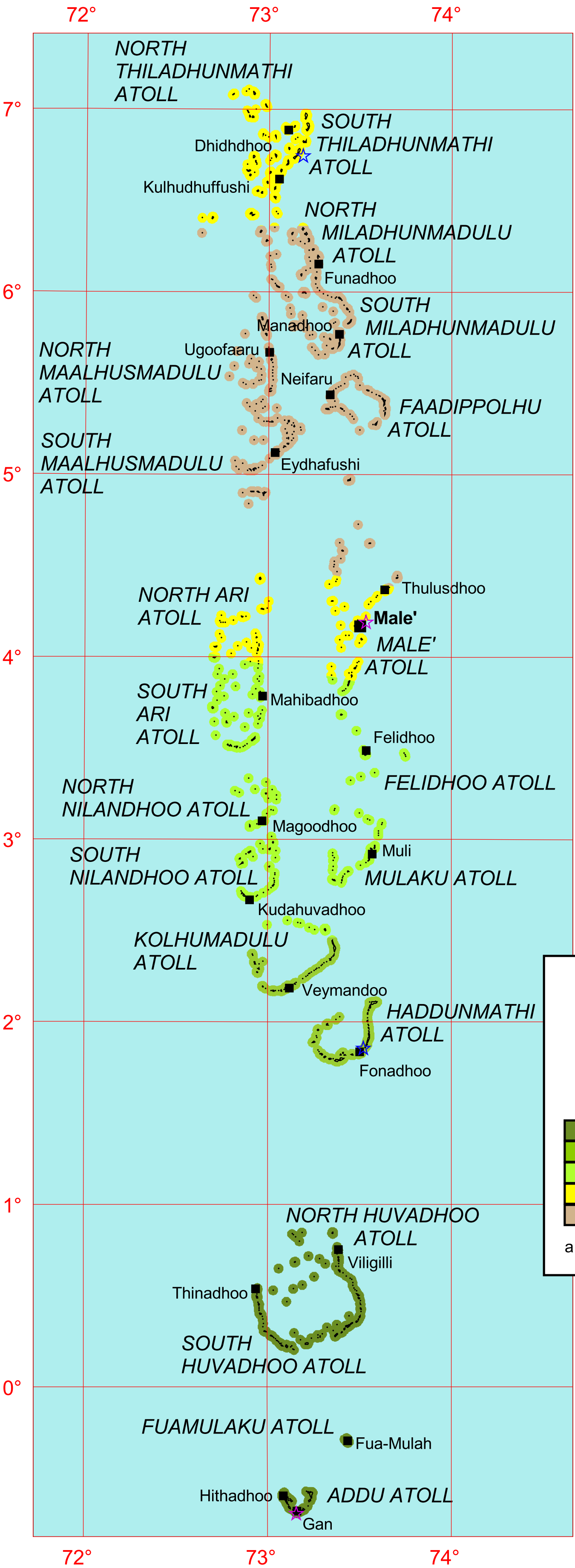
The northeast monsoon weakens south of the Male' area and by Addu Atoll at the southern extreme of the Maldives the prevailing direction is westerly most of the year. During December through March the winds are from the northwest replacing the northeast winds observed further north. The northwest winds also re-appear in July and August, though in some years southerly winds prevail during these months. Winds more from the due west prevail from April through June and in October and November. September is a transition month with characteristics of the westerly and northwesterly flow. The strongest winds occur during the months the winds are most westerly.

8.3.2 Seasonal Wind Resource Distribution

The extreme northern part of the Maldives has a distinct resource maximum from May through October during the west monsoon with the highest resource in June and July. The resource during the rest of the year is significantly lower and reaches the lowest resource during March and April. The seasonal distribution changes as you move south. The highest wind resource area between Male' and North Miladhunmadulu Atoll has a more even distribution throughout the year. Several factors contribute to this change in the seasonal distribution. The resource in July and August decreases compared to northern part of the Maldives, but the strengthening of the northeast monsoon between December and February and the west monsoon in September and October compensates for the decrease. The net result is a seasonal distribution with broad resource maximums from May through October, slightly peaking in June, and a secondary resource maximum in December and January. The trend of decreasing resource in July and August continues as one moves south and the northeast monsoon disappears. At Addu Atoll, the seasonal distribution is bimodal. There are wind resource maximums in April and May and from September through November. The peak wind resource month at Addu Atoll is October instead of June as is found in the central and northern Maldives. June and July have a relative minimum of resource in the southern Maldives instead of a maximum of resource in these months in the northern Maldives. Figure 8.2 shows the seasonal wind pattern from the satellite ocean data covering the northern through the southern regions of the Maldives. The Appendices contain tables and plots of wind characteristics from stations in the Maldives (Appendices A and B), upper-air data from Minicoy Island (India), Male', and Gan Island (Appendix D), and ocean satellite data maps for the area (Appendix E). As shown by the interannual plots of the ocean satellite data included in Appendix E, not all years have close to the long-term average wind resource. For example, the year 1997 was an abnormally low wind resource year throughout the Maldives with little spatial variation. This shows that long-term ocean satellite wind data can be used to examine whether short-term data (such as one year) from measurement sites are truly representative of the long-term wind resource.

Because the ocean influence is so strong in the Maldives the diurnal pattern at 50 m will be typical of marine locations. The diurnal speed and power profiles will be flat with a tendency for the maximum speed and power to occur at night.

Maldives
Wind Resource Map



This wind resource classification is specific for large scale and small scale applications.

Wind Power Classification

Resource Potential Large	Resource Potential Small	Wind Power Density at 50 m W/m²	Wind Speed[a] at 50 m m/s
Fair	Moderate	225 - 250	5.8 - 6.0
Fair	Moderate	250 - 275	6.0 - 6.2
Fair	Moderate	275 - 300	6.2 - 6.4
Moderate	Good	300 - 325	6.4 - 6.5
Moderate	Good	325 - 350	6.5 - 6.7

[a] Wind speeds are based on a Weibull k value of 2.0

50 0 50 100 150 200 Kilometers

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16-JUN-2003 1.8.1

Figure 8-1

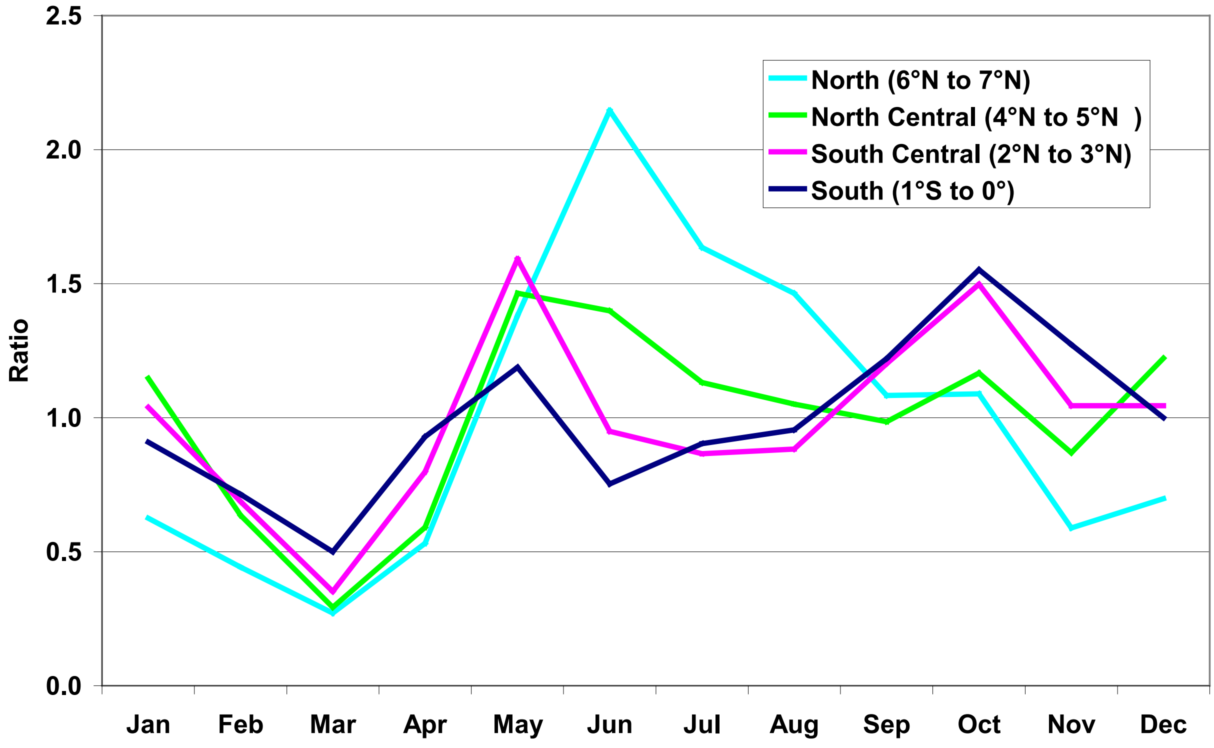

Figure 8.2 Maldives – Monthly Ratio (Month/Annual) of Wind Power Density.

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Appendix A:

Surface Meteorological Stations
Tables and Analysis Summaries of Selected Stations

Table A.1 Surface Meteorological Stations in Sri Lanka

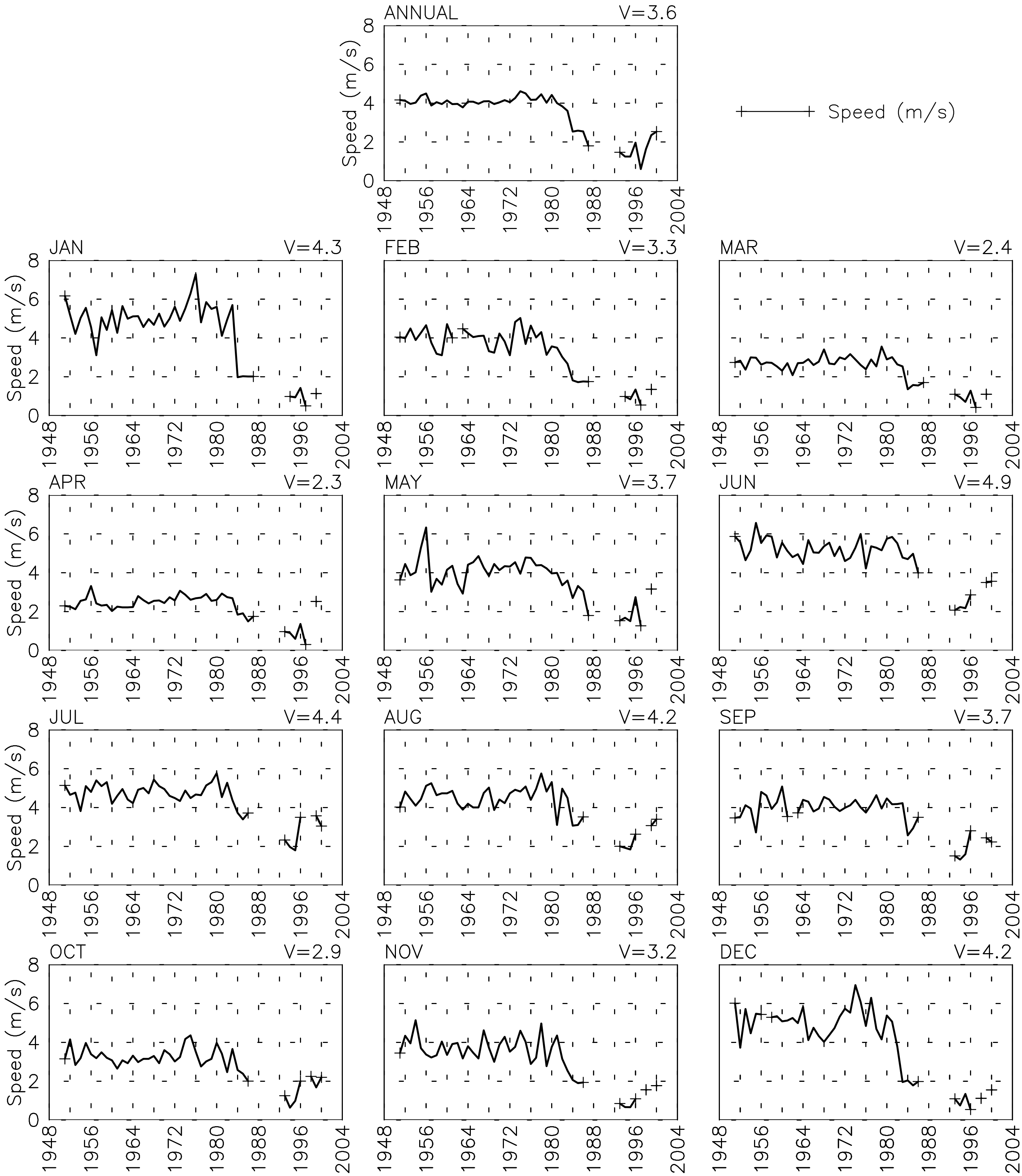
Name	Lat N	Lon E	Elev	A Ht	From	To	% Data	WS (avg)	WS (max5)	YR (max5)
Trincomalee	08 35	81 15	3	4.2	1951/01	2000/12	84%	3.59	4.38	1974
Anuradhapura	08 20	80 25	91	4.2	1952/07	2000/12	98%	2.02	2.58	1971
Mahailluppallama	08 05	80 28	136	3	1952/11	2000/12	84%	2.25	3.28	1953
Mannar	08 53	79 55	4	6	1951/01	2000/12	94%	3.57	4.00	1967
Puttalam	08 02	79 50	2	6	1951/01	2000/12	99%	3.17	3.93	1975
Batticoloa	07 43	81 42	3	6	1951/01	2000/12	94%	2.67	3.00	1964
Nuwara-Eliya	06 50	80 46	1865	6	1960/12	2000/12	99%	2.42	2.98	1960
Bandarawela	06 50	80 59	1225	6	1951/01	2000/12	98%	1.57	2.29	1991
Katunayaka	07 10	79 53	8	6	1988/01	2000/12	97%	2.41	2.61	1988
Colombo	06 54	79 52	7	6	1951/01	2000/12	100%	1.86	2.49	1951
Ratmalana	06 49	79 53	5	6	1951/01	1985/08	98%	2.14	2.40	1951
Hambantota	06 07	81 08	15	3	1951/01	2000/12	96%	5.61	5.95	1964
Kankasanthurei	09 49	80 04	14	2.6	1950/01	1988/01	98%	3.59	4.36	1950
Mulativu	09 16	80 50		6	1980/03	1989/12	97%	2.76	2.92	1985

SPEED BY YEAR

Trincomalee – 000001

8° 35' N 81° 15' E – Elev 3m LST=GMT+99 hours *NT= +5

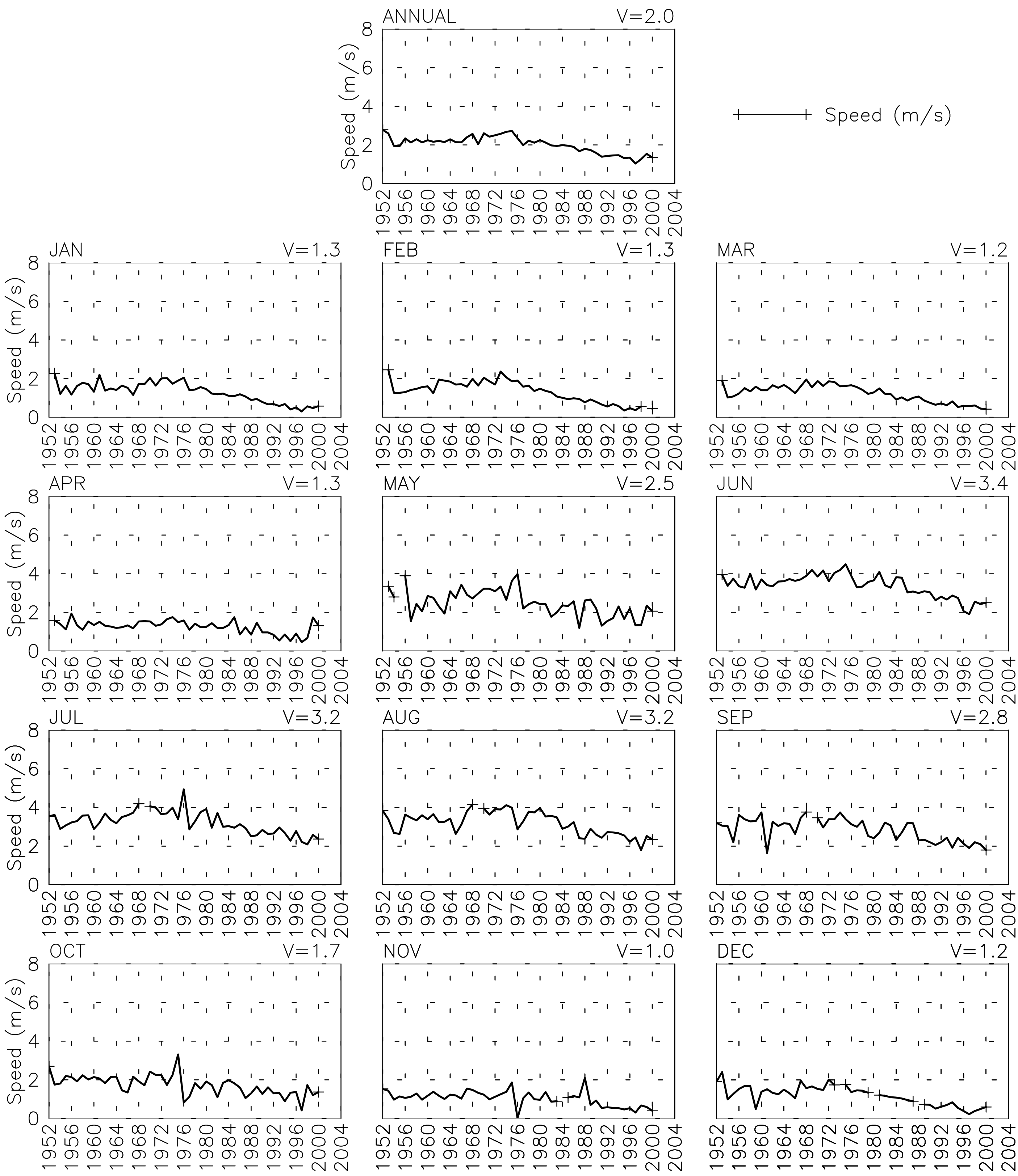
01/51–05/87 03/93–12/00



Wed Jun 25 12:12:39 2003

SPEED BY YEAR

Anuradhapura – 000002
8° 20' N 80° 25' E – Elev 91m LST=GMT+99 hours *NT= +5
07/52–12/00



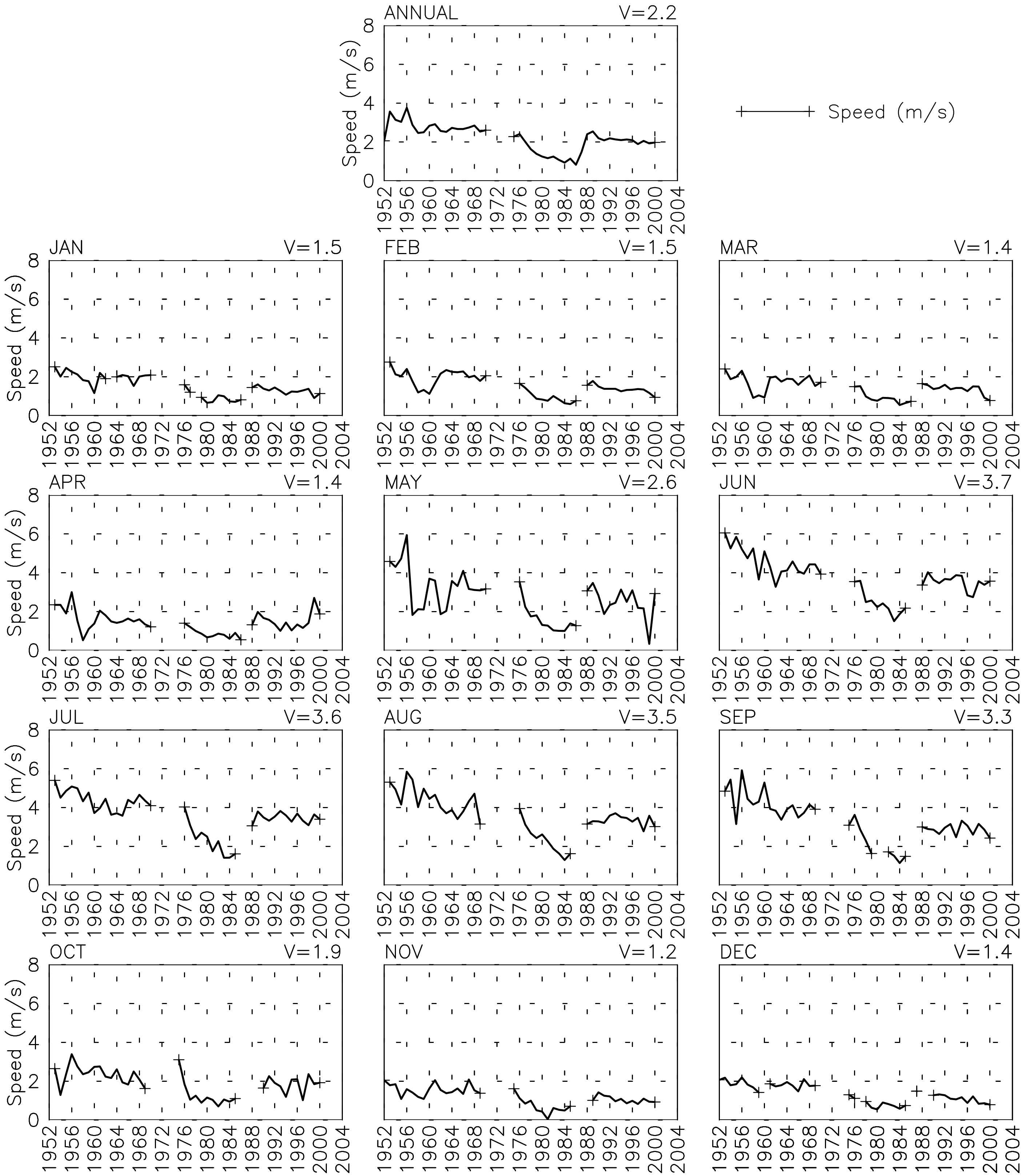
Wed Jun 25 12:12:40 2003

SPEED BY YEAR

Mahailluppallama – 000003

8° 05' N 80° 28' E – Elev 136m LST=GMT+99 hours *NT= +5

11/52–07/70 09/75–12/00



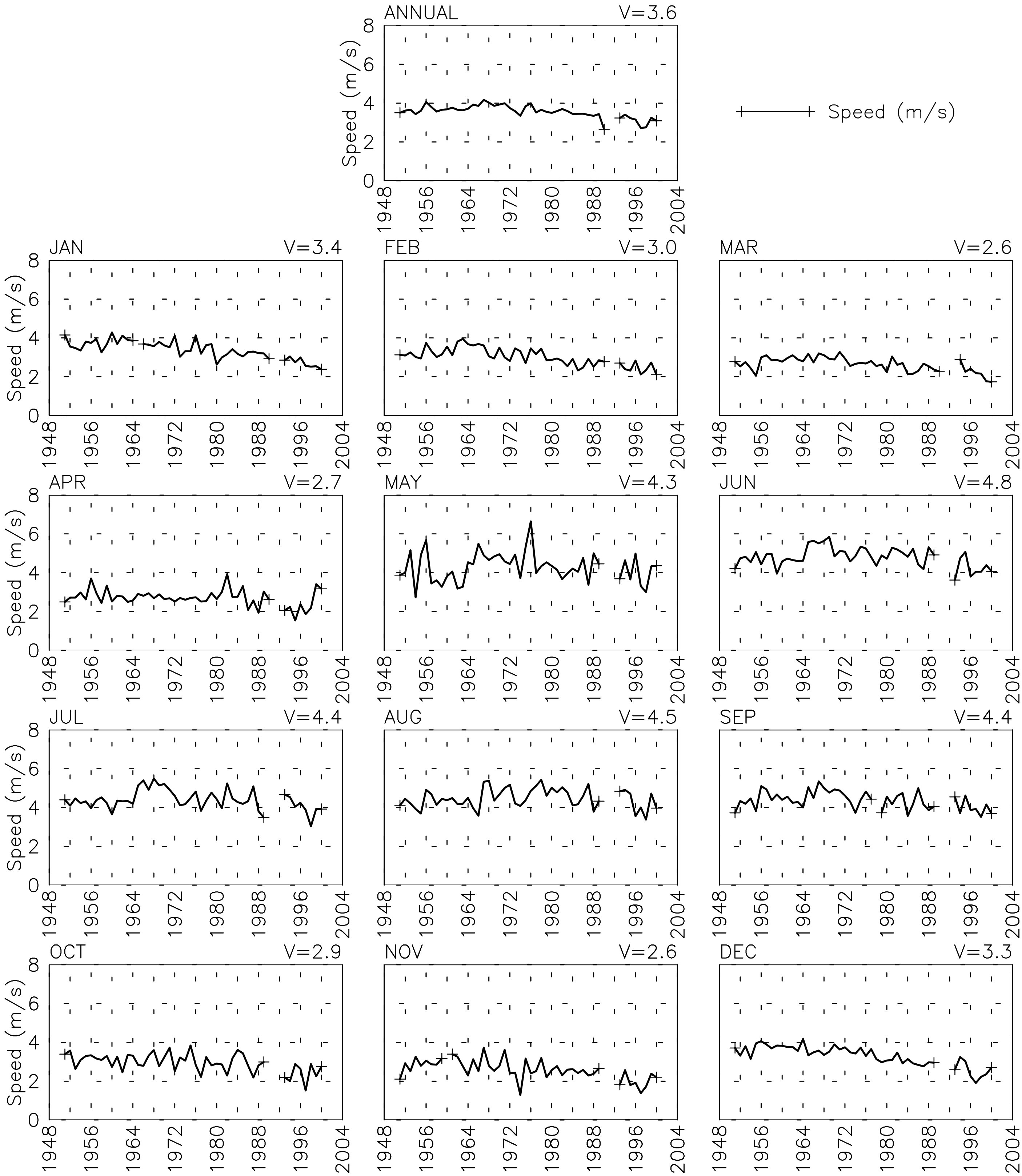
Wed Jun 25 12:12:42 2003

SPEED BY YEAR

Mannar – 000004

8° 53' N 79° 55' E – Elev 4m LST=GMT+99 hours *NT= +5

01/51–04/90 01/93–12/00



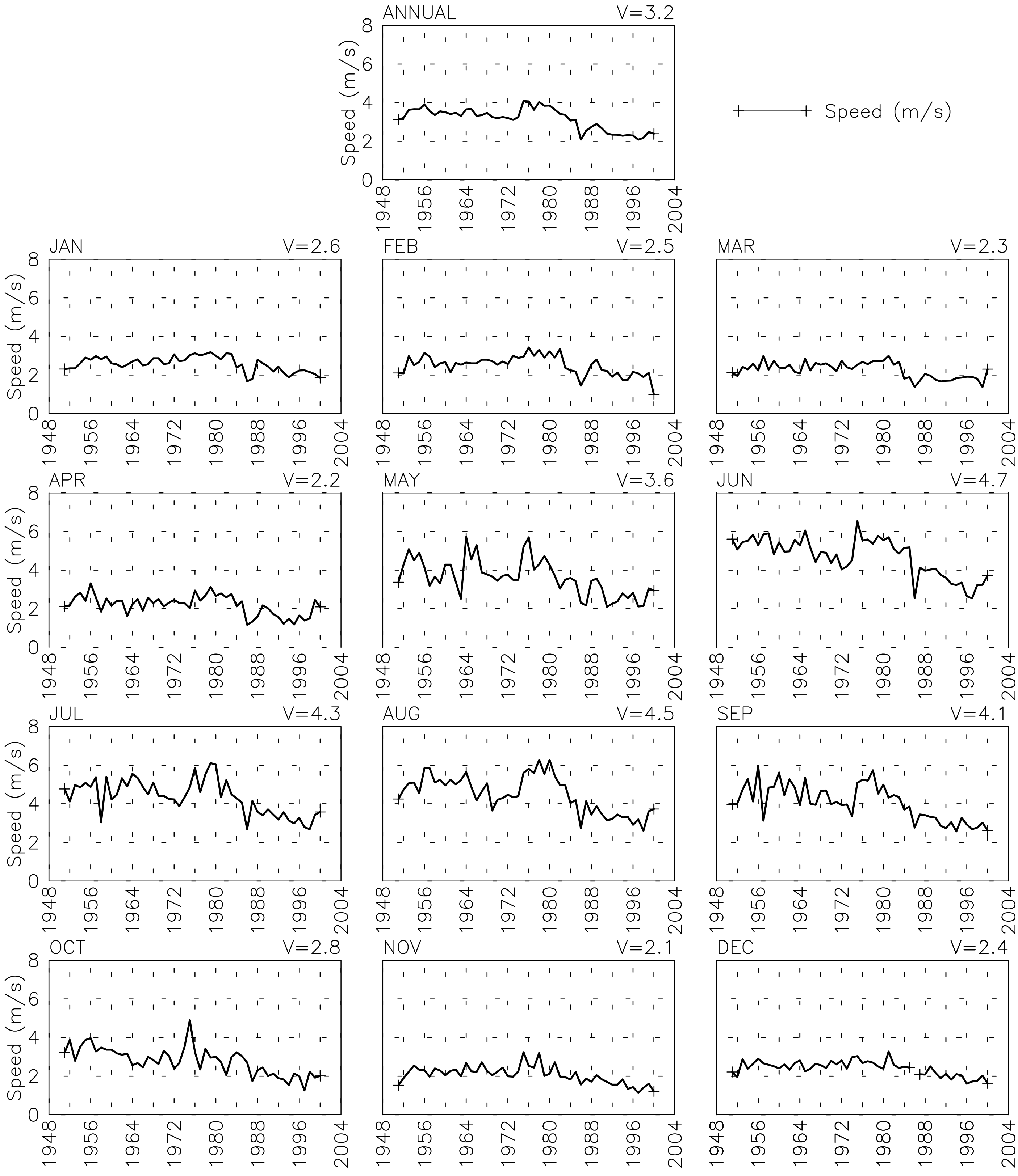
Wed Jun 25 12:12:43 2003

SPEED BY YEAR

Puttalam - 000005

8° 02' N 79° 50' E - Elev 2m LST=GMT+99 hours *NT= +5

01/51-12/00



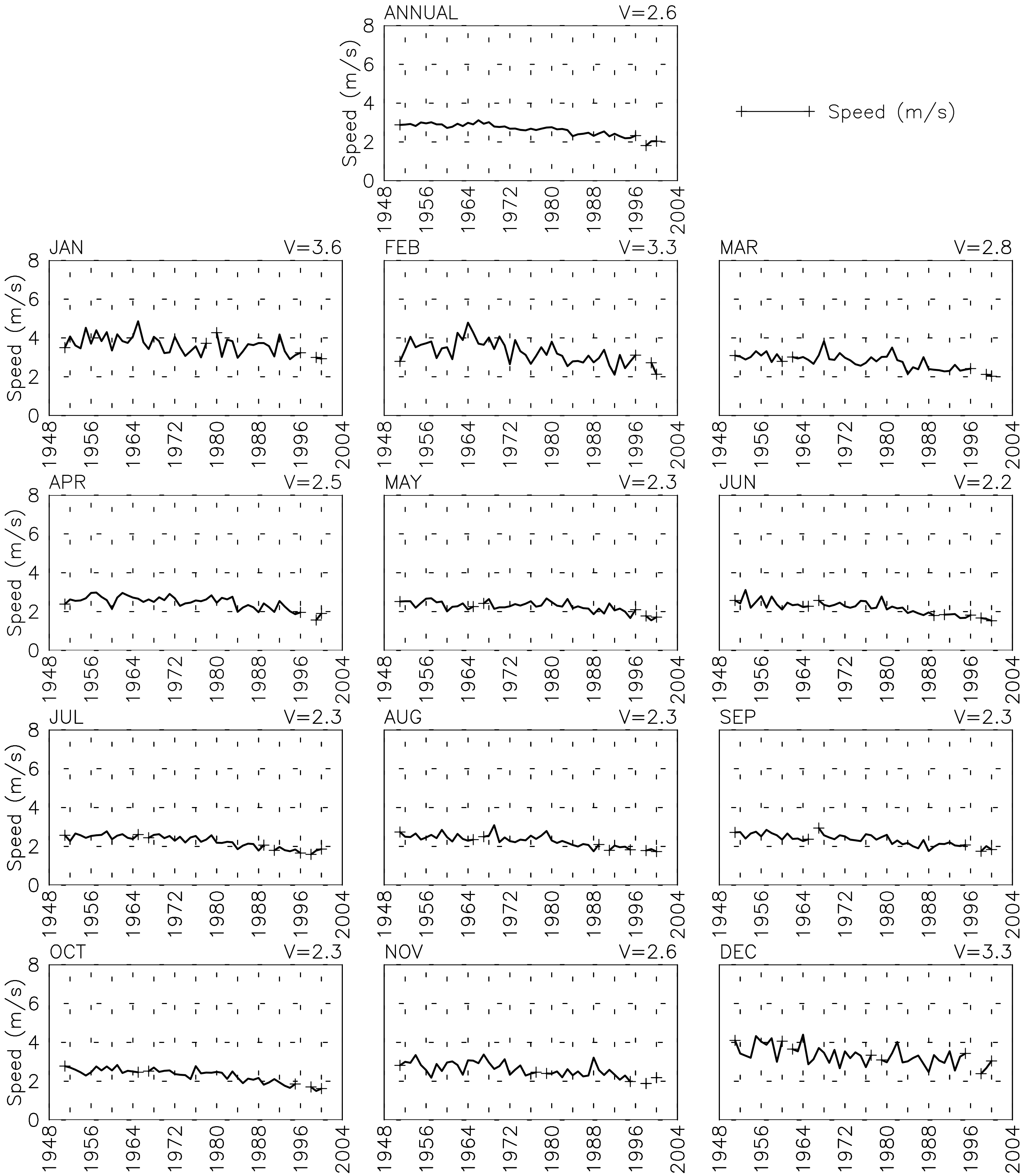
Wed Jun 25 12:12:45 2003

SPEED BY YEAR

Batticoloa – 000006

7° 43' N 81° 42' E – Elev 3m LST=GMT+99 hours *NT= +5

01/51–07/96 05/98–12/00



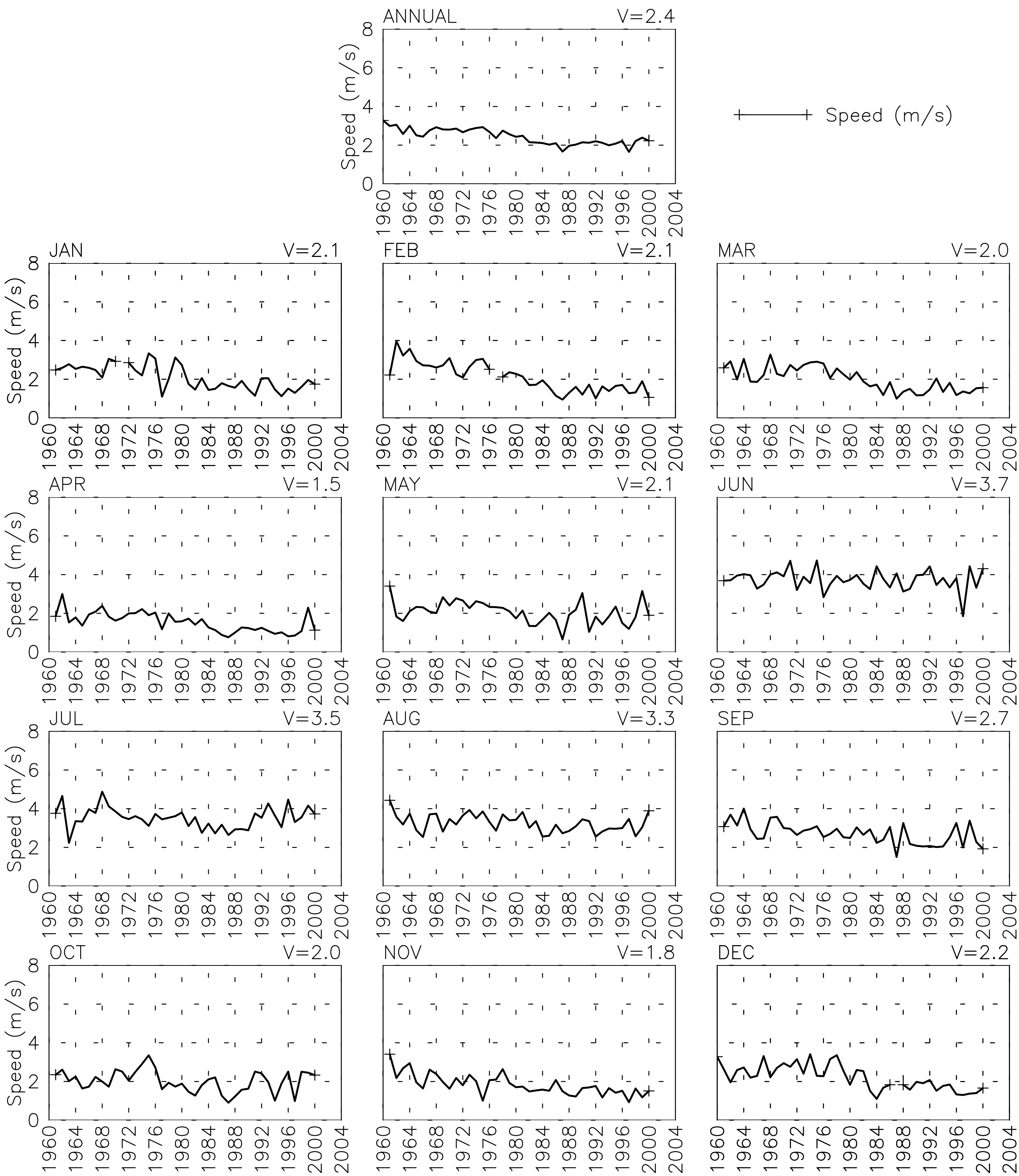
Wed Jun 25 12:12:46 2003

SPEED BY YEAR

Nuwara-Eliya - 000007

6° 50' N 80° 46' E - Elev 1865m LST=GMT+99 hours *NT= +5

12/60-12/00



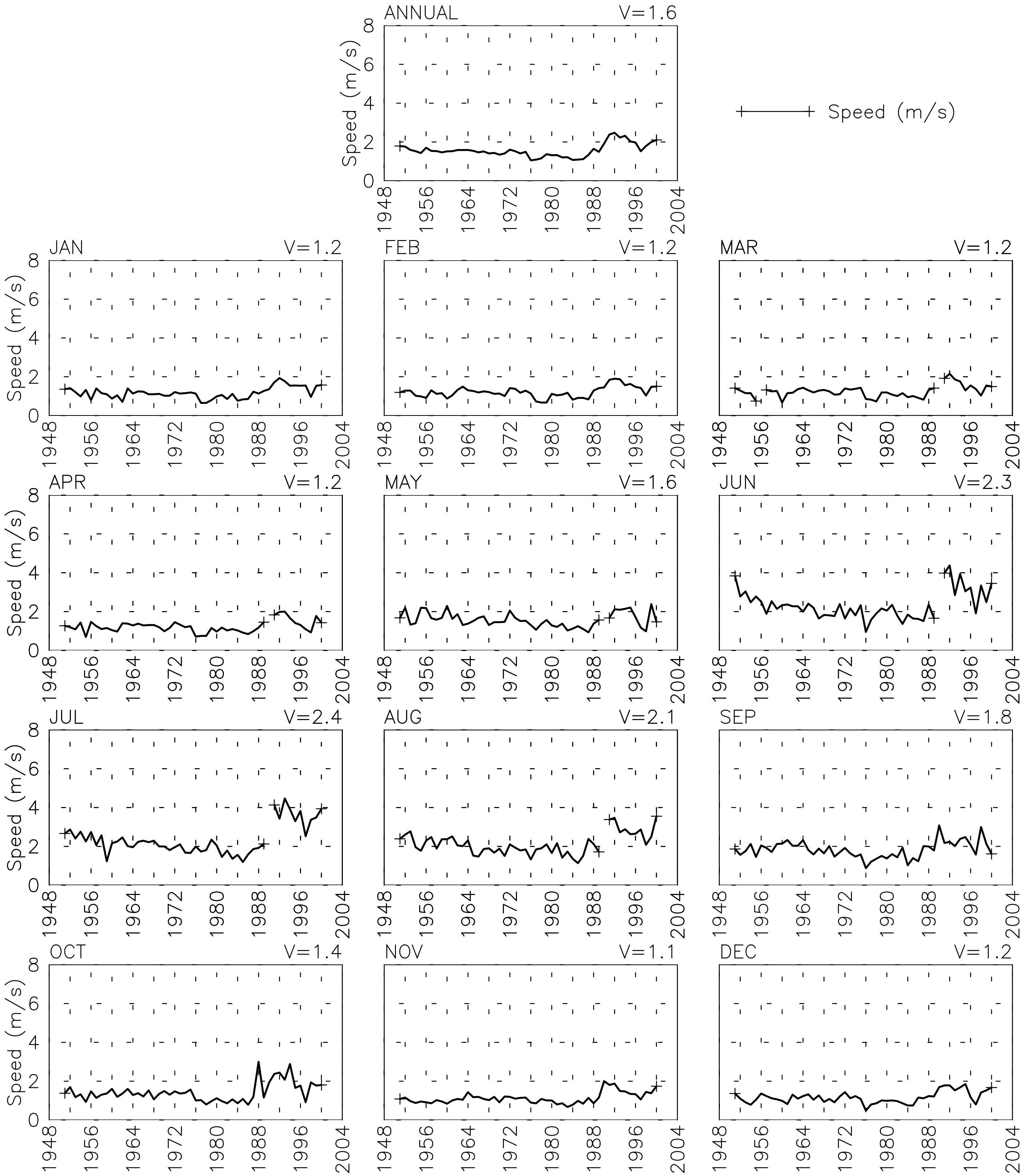
Wed Jun 25 12:12:48 2003

SPEED BY YEAR

Bandarawela - 000008

6° 50' N   80° 59' E - Elev 1225m   LST=GMT+99 hours   *NT= +5

01/51-12/00



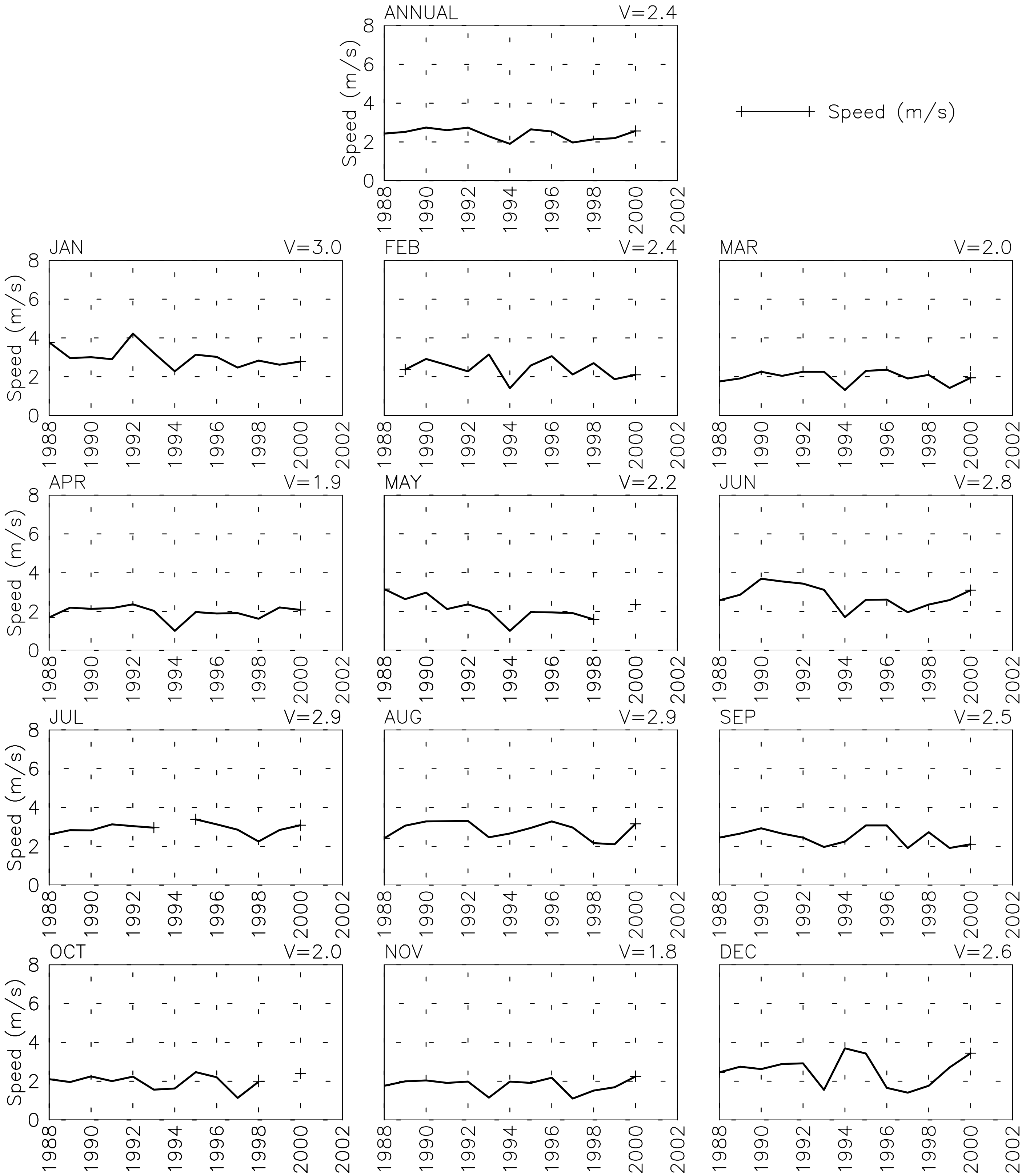
Wed Jun 25 12:12:49 2003

SPEED BY YEAR

Katunayaka - 000009

7° 10' N 79° 53' E - Elev 8m LST=GMT+99 hours *NT= +5

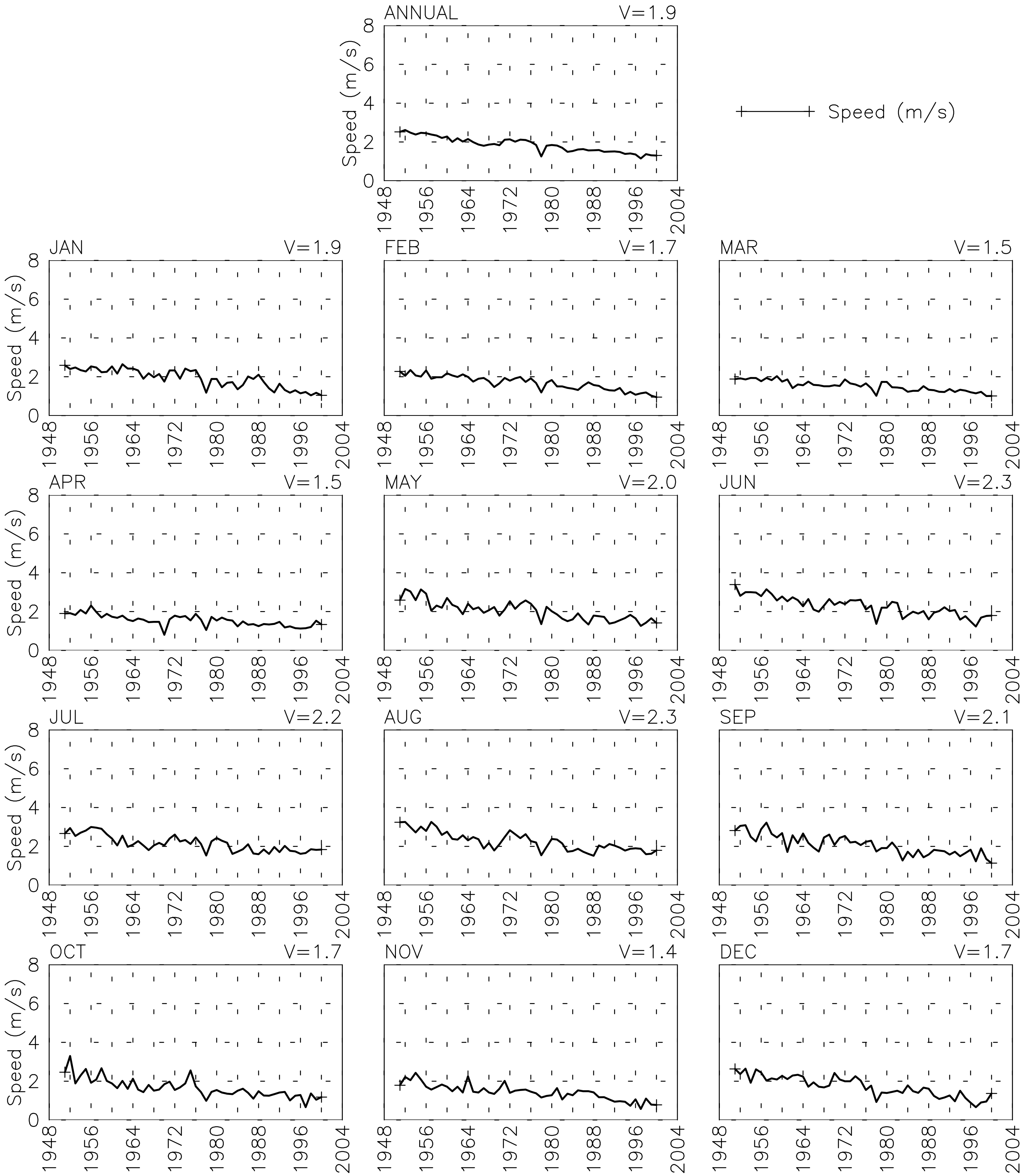
01/88-12/00



Wed Jun 25 12:12:50 2003

SPEED BY YEAR

Colombo – 000010
6° 54' N   79° 52' E – Elev   7m   LST=GMT+99 hours   *NT= +5
01/51–12/00



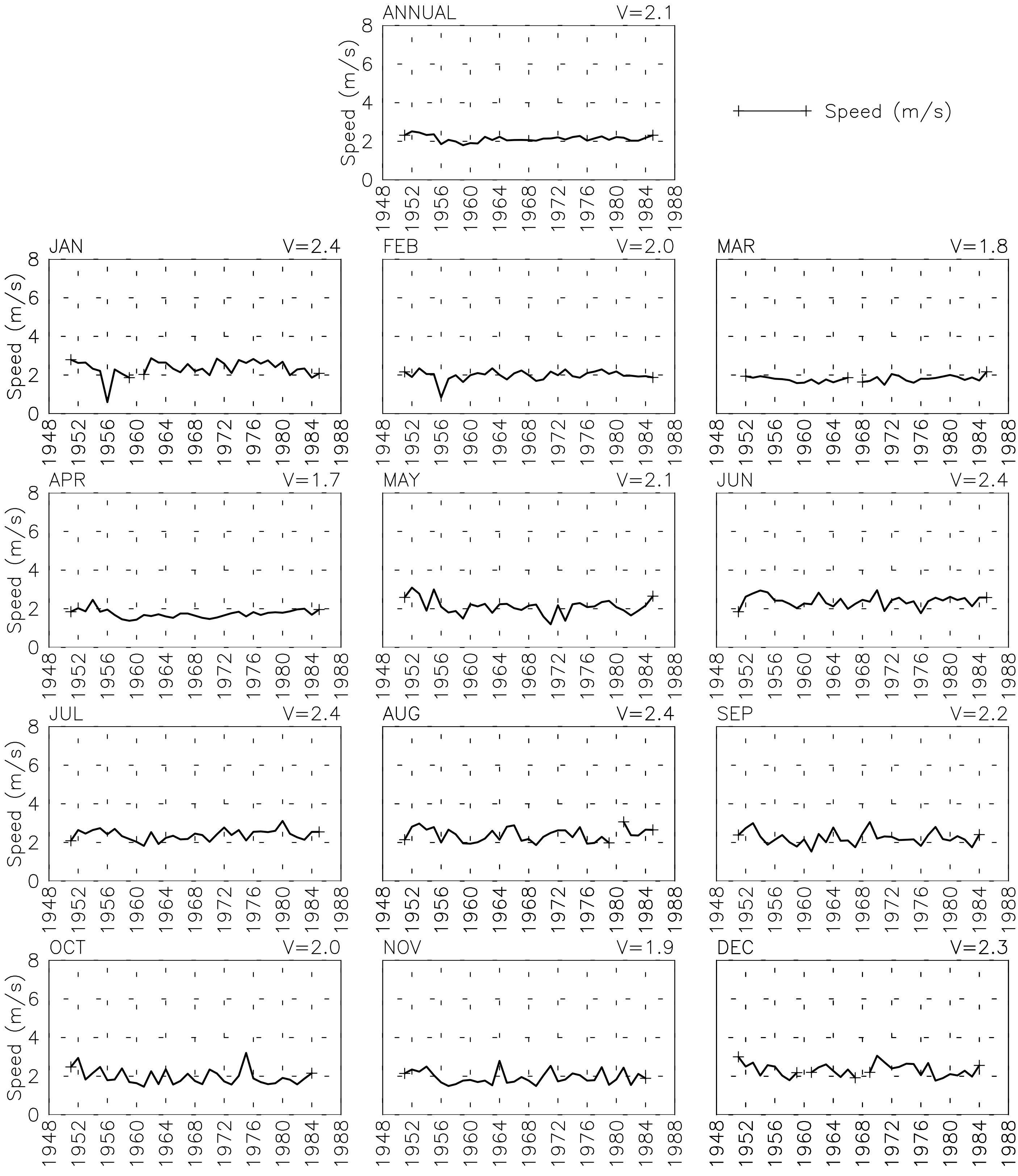
Wed Jun 25 12:12:52 2003

SPEED BY YEAR

Ratmalana – 000011

6° 49' N 79° 53' E – Elev 5m LST=GMT+99 hours *NT= +5

01/51–08/85



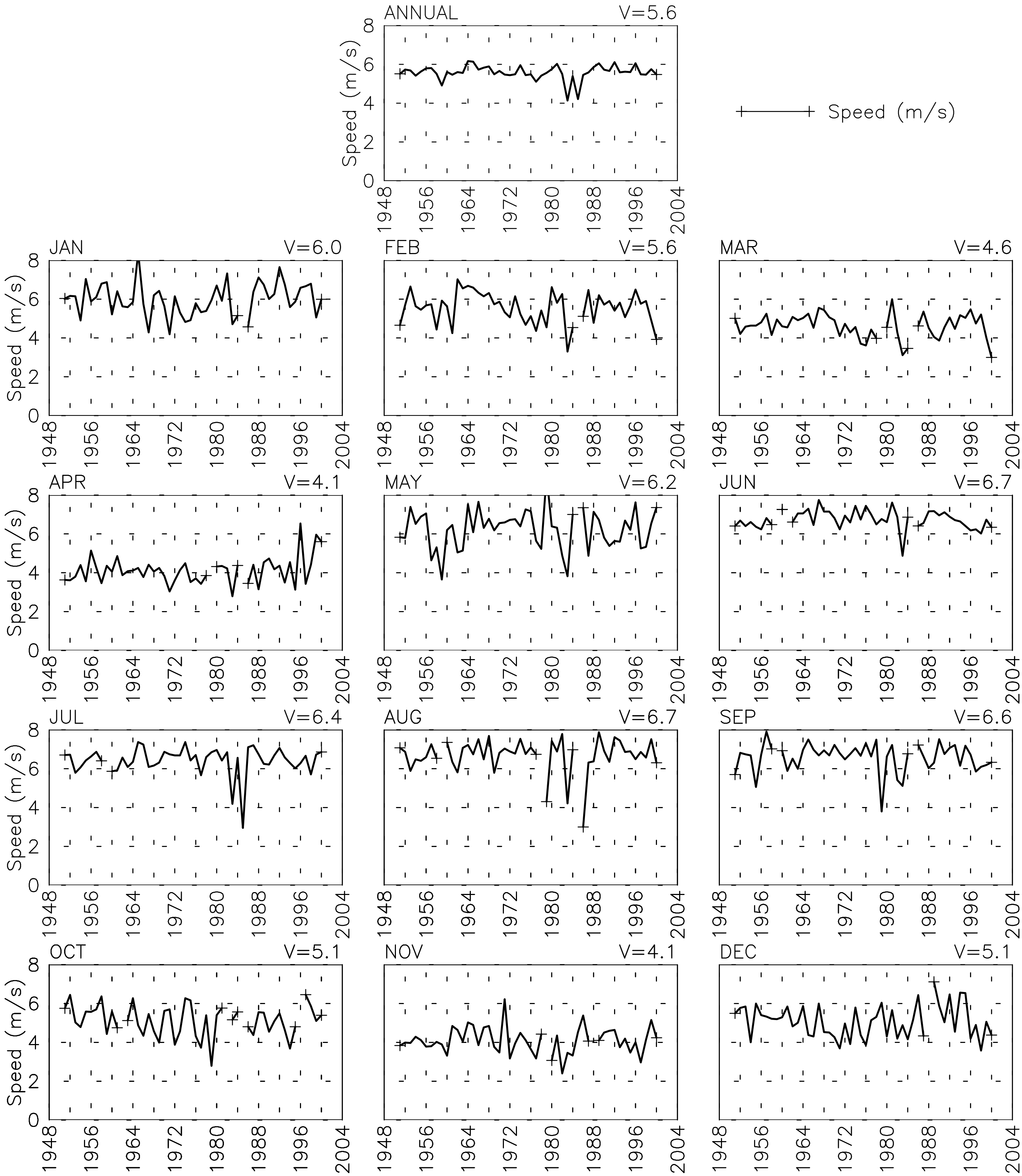
Wed Jun 25 12:12:53 2003

SPEED BY YEAR

Hambantota – 000012

6° 07' N 81° 08' E – Elev 15m LST=GMT+99 hours *NT= +5

01/51–12/00

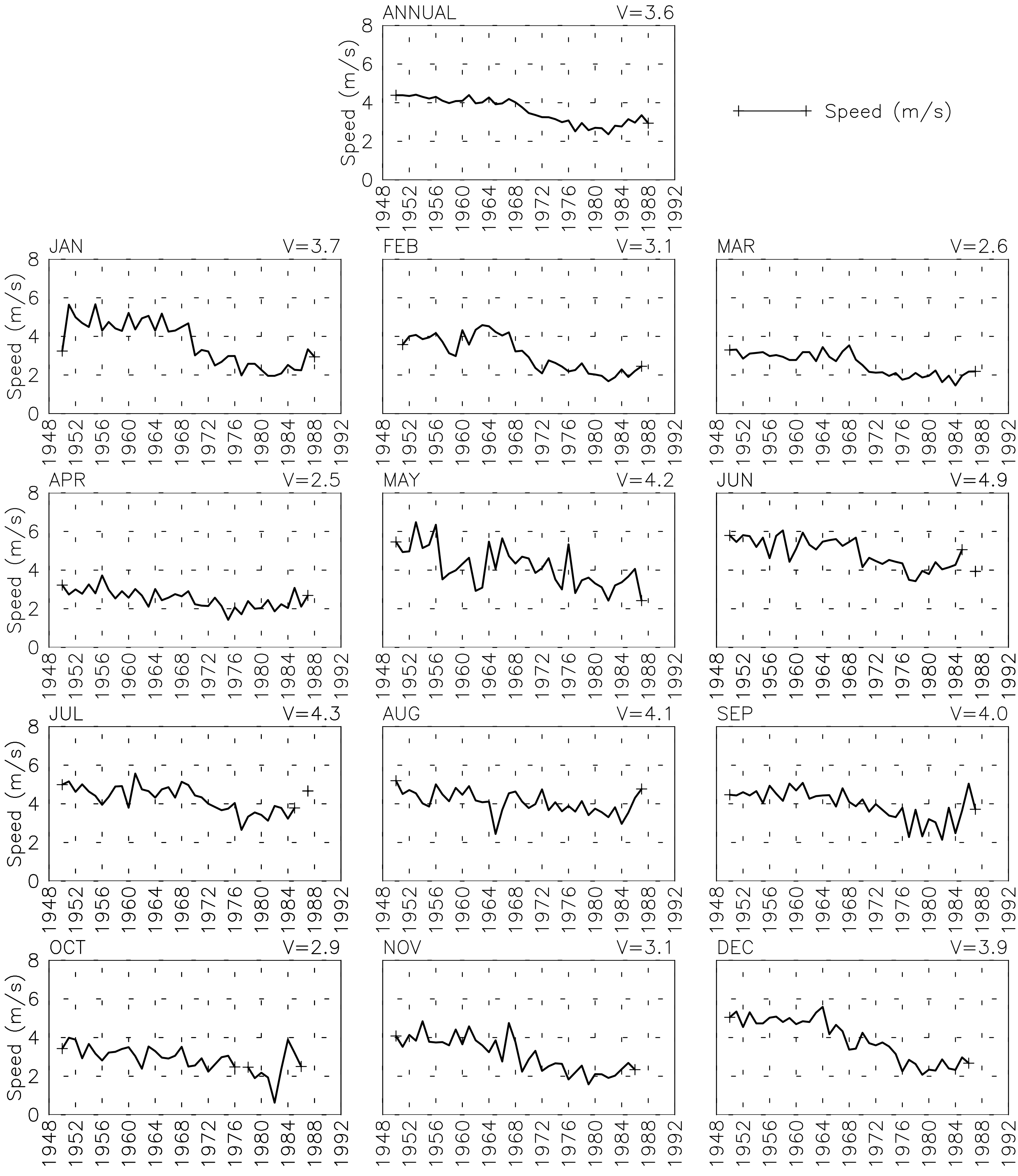


SPEED BY YEAR

Kankasanthurei – 000013

9° 49' N 80° 04' E – Elev 14m LST=GMT+99 hours *NT= +5

01/50–01/88



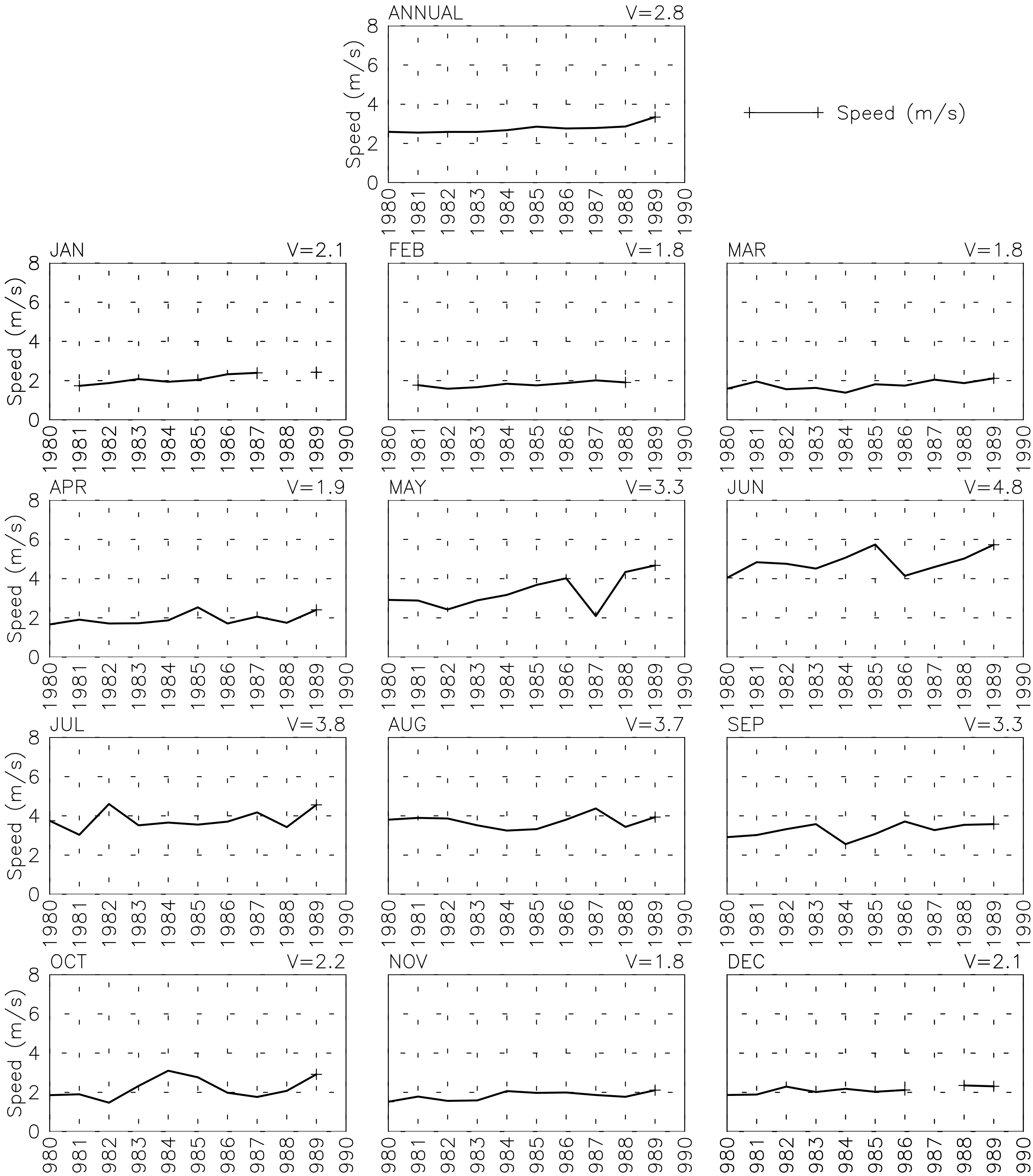
Wed Jun 25 12:12:55 2003

SPEED BY YEAR

Mulativu – 000014

9° 16' N 80° 50' E – Elev 9999m LST=GMT+99 hours *NT= +5

03/80–12/89



Wed Jun 25 12:12:56 2003

Table A.2 Surface Meteorological Stations in the Maldives

Name	Lat N	Lon E	Elev	From	To	Nrec	%Data	WS (avg)
Hanimadu	6 45	73 11	1	1992/01	2001/12	108	90%	4.22
Hulule	4 12	73 31	2	1987/01	2001/12	180	100%	5.25
Kadhdoo	1 52	73 31	2	1992/01	2001/12	120	100%	3.85
Gan Island	-0 42	73 09	2	1987/01	2001/12	168	93%	3.85

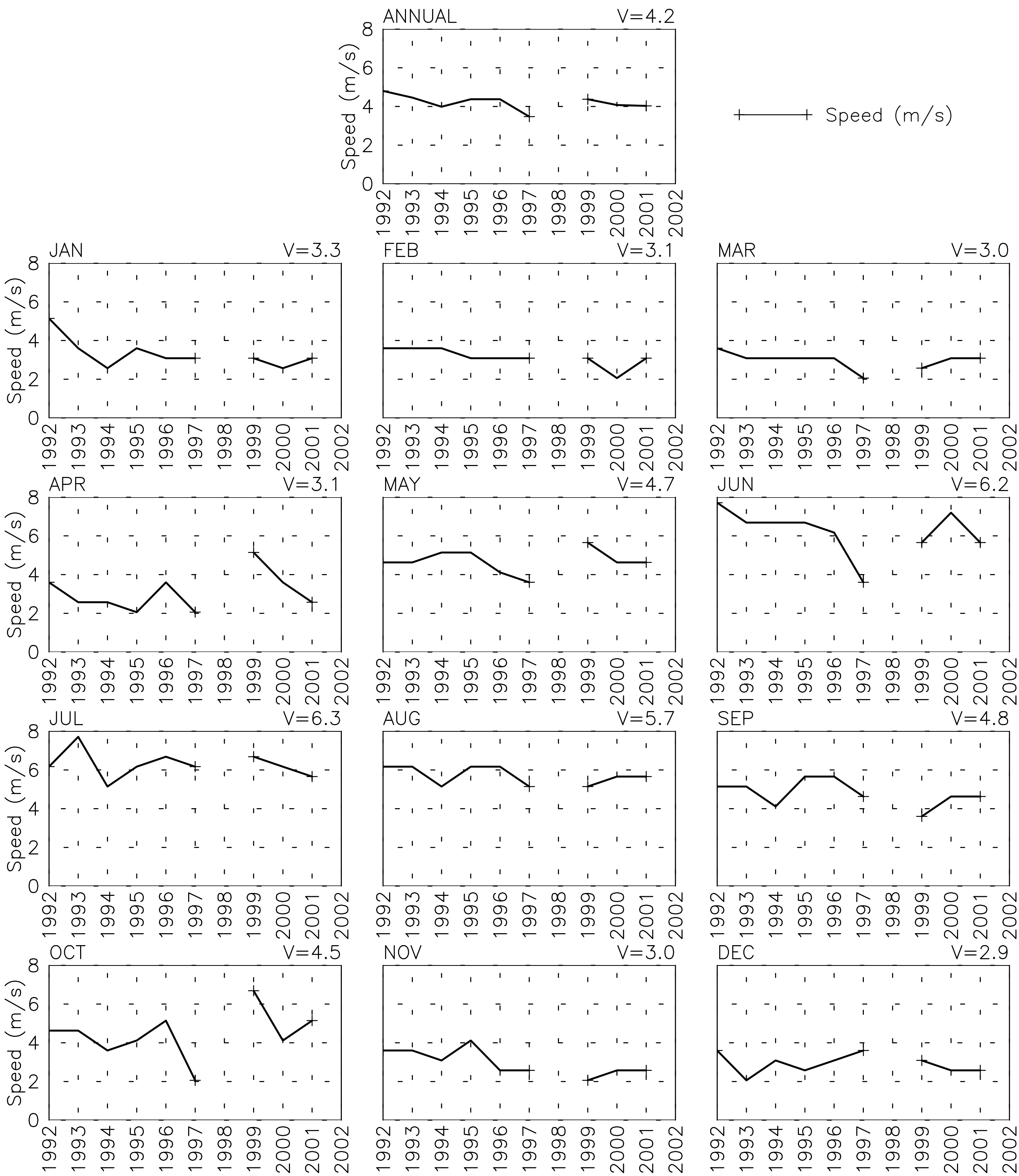
Latitude (Lat N) and longitude (Lon E) are in degrees and minutes. Elevations (Elev) are in meters above sea level. Aht is the anemometer height I meters above ground level. Nrec is the number of monthly data records present. %Data is the percent of records present compared to the number of months in the entire period of record. WS (avg) is the averal annual wind speed in meters per second. WS (max5) is the maximum 5=year average wind speed for the data set, and YR (max5) is the year that the 5-year period began.

SPEED BY YEAR

HANIMADU MV - 000001

6° 45' N 73° 11' E - Elev 1m LST=GMT+99 hours *NT= +5

01/92-12/97 01/99-12/01



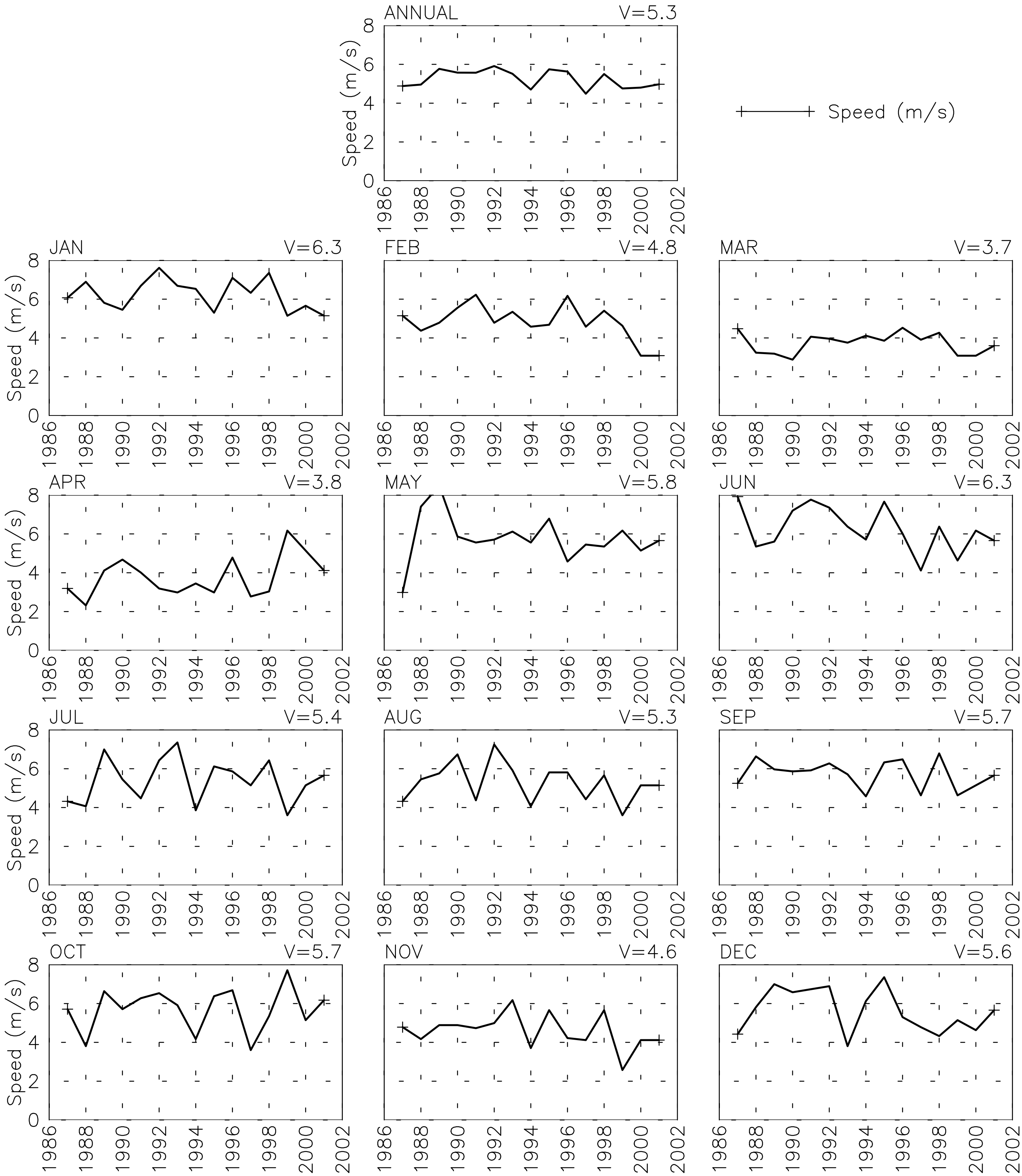
Wed Jun 25 10:29:36 2003

SPEED BY YEAR

HULULE MV - 000002

4° 11' N 73° 32' E - Elev 2m LST=GMT+99 hours *NT= +5

01/87-12/01



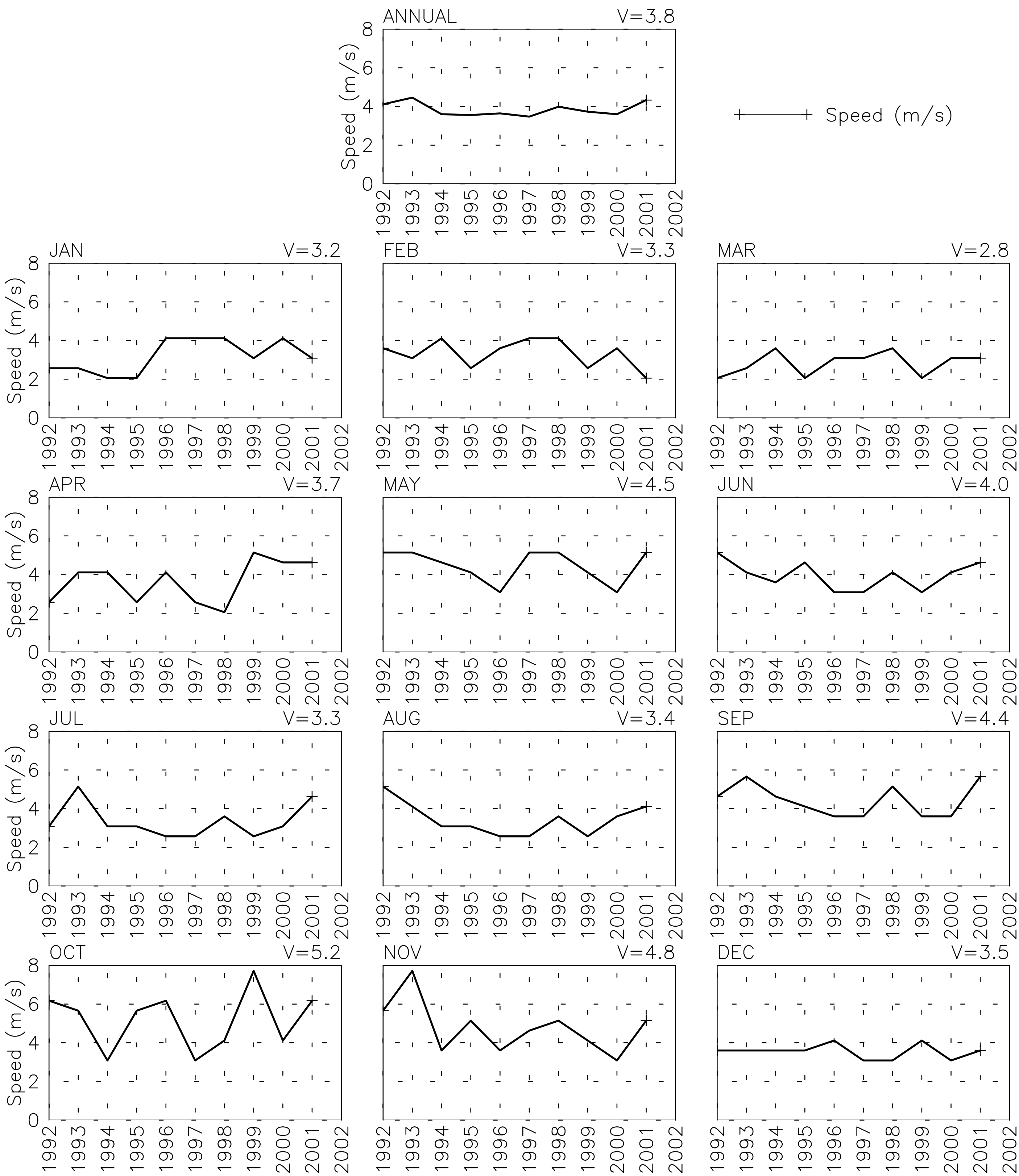
Wed Jun 25 10:29:37 2003

SPEED BY YEAR

KADHDOO MV – 000003

1° 51' N 73° 31' E – Elev 1m LST=GMT+99 hours *NT= +5

01/92–12/01



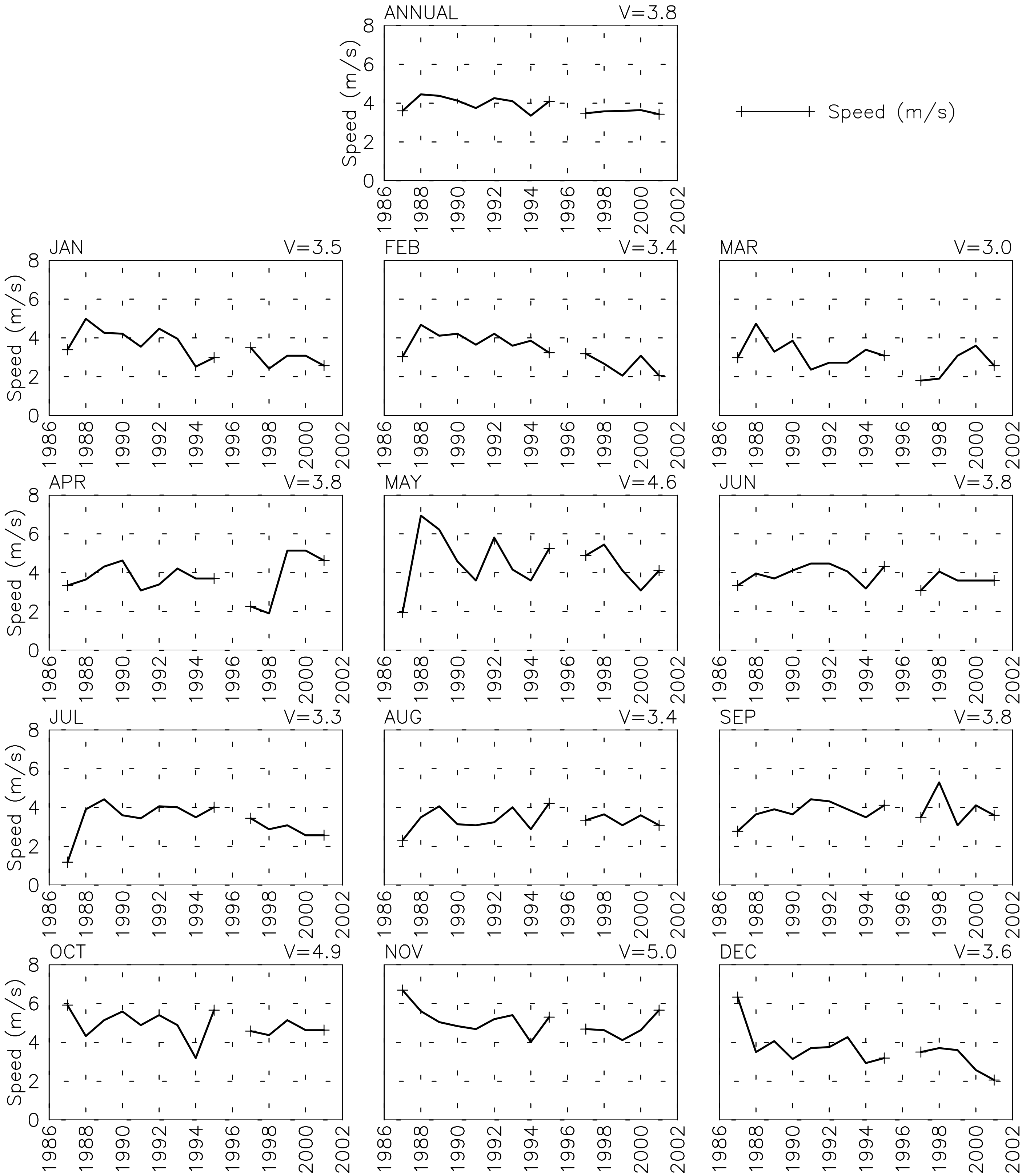
Wed Jun 25 10:29:38 2003

SPEED BY YEAR

GAN ISLAND MV – 000004

0° 42' N 73° 09' E – Elev 2m LST=GMT+99 hours *NT= +5

01/87–12/95 01/97–12/01



Wed Jun 25 10:29:39 2003

Appendix B:

Surface Meteorological Stations
Tables and Analysis Summaries of Selected Stations

DATSAV2 Stations

Table B.1 DATSAV Stations in Sri Lanka

Name	ID	Lat N	Lon E	Elev	From	To	Nrec	%Data	WS (avg)	WPDavg
KANKESANTURAI (AFB)	434000	9 48	80 04	15	1956/01	1986/01	37318	14%	3.54	53.4
MANNAR	434130	8 59	79 55	3	1957/07	1996/12	17260	4%	3.48	50.8
TRINCOMALEE (AFB)	434180	8 35	81 15	7	1945/08	1996/12	53344	11%	4.02	84.5
ANURADHAPURA (AFB)	434210	8 19	80 25	89	1962/01	1996/12	24002	7%	1.47	11.2
PUTTALAM	434240	8 02	79 50	2	1959/01	1996/12	48833	14%	2.93	45.7
BATTICALOA (AFB)	434360	7 43	81 42	12	1957/07	1996/12	45984	13%	2.61	33.0
COLOMBO/KATUNAYAKE	434500	7 10	79 53	8	1962/01	1996/12	60714	19%	3.58	66.0
COLOMBO	434660	6 54	79 52	7	1944/01	1996/12	28159	6%	2.17	17.9
COLOMBO/RATMALANA	434670	6 49	79 53	5	1944/05	1996/12	69535	15%	2.77	76.8
NUWARA ELIYA	434730	6 58	80 45	1880	1957/07	1996/12	45376	13%	1.85	18.7
HAMBANTOTA	434970	6 07	81 08	20	1945/08	1996/12	58819	13%	6.60	259.4

Table B.2 DATSAV Stations in the Maldives

Name	ID	Lat N	Lon E	Elev	From	To	Nrec	%Data	WS (avg)	WP (avg)
HANIMADU	435330	6 44	73 09	1	1993/08	1996/12	3522	11%	4.28	95.2
MALE' INTL/HULULE IS	435550	4 12	73 31	2	1983/01	1996/12	18249	14%	5.47	177.1
KADHDOO	435770	1 53	73 30	2	1994/08	1996/12	2145	10%	3.67	72.6
GAN ISLAND	435990	-0 41	73 09	2	1985/01	1996/12	21732	20%	4.02	81.4

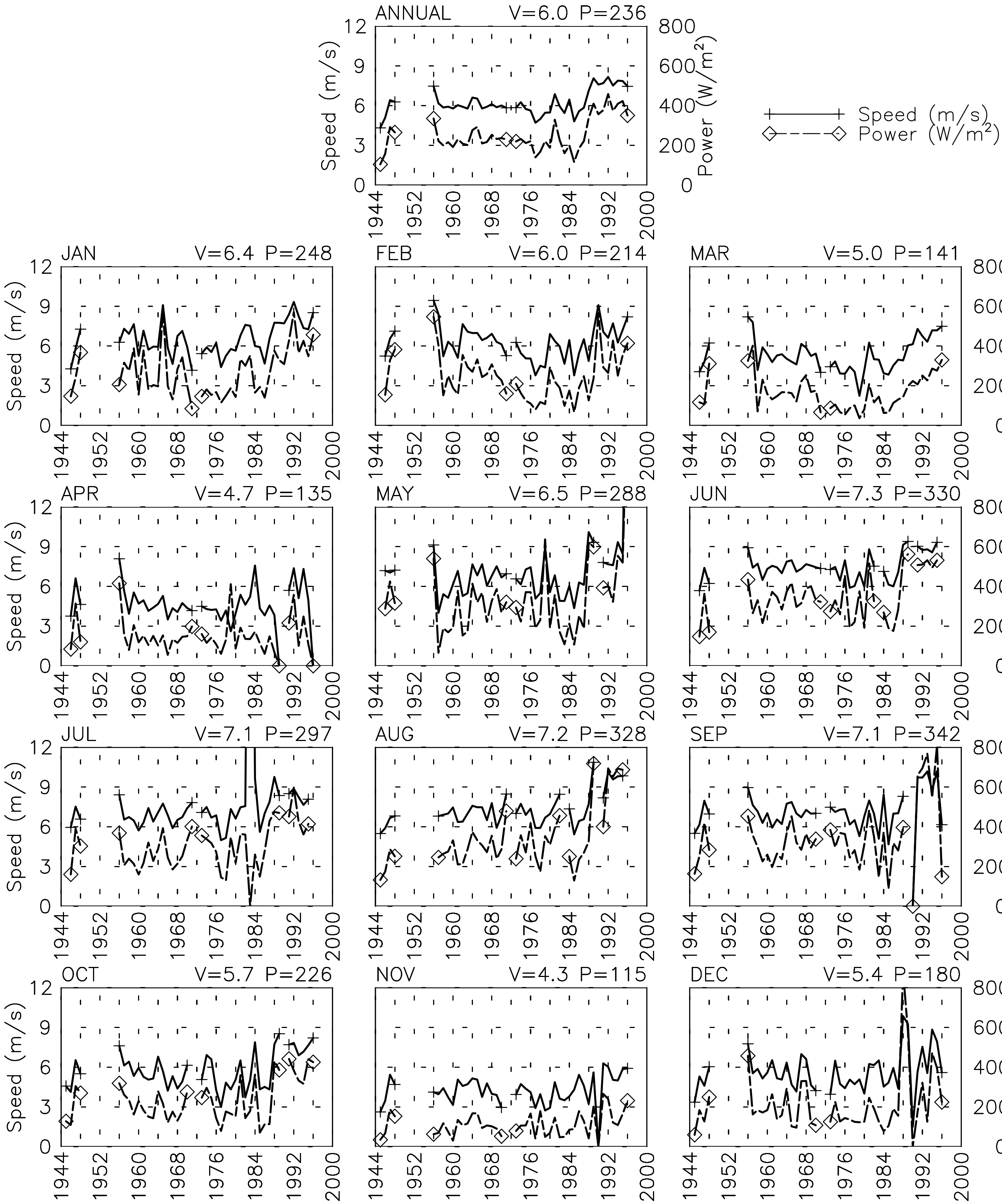
Latitude north (Lat N) and longitude (Lon E) are in degrees and minutes. Elevations (Elev) are in meters above sea level. Nrec is the number of hourly data records present. %Data is the percent of records present compared to the number of hours in the entire period of record. WS (avg) is the average wind speed in meters per second. WP (avg) is the average wind power density in watts per square meters.

SPEED AND POWER BY YEAR

HAMBANTOTA CL – 434970

6° 07' N 81° 08' E – Elev 20m *LST=GMT +5 hours NT= +5

08/45–12/48 01/56–08/71 01/73–12/96



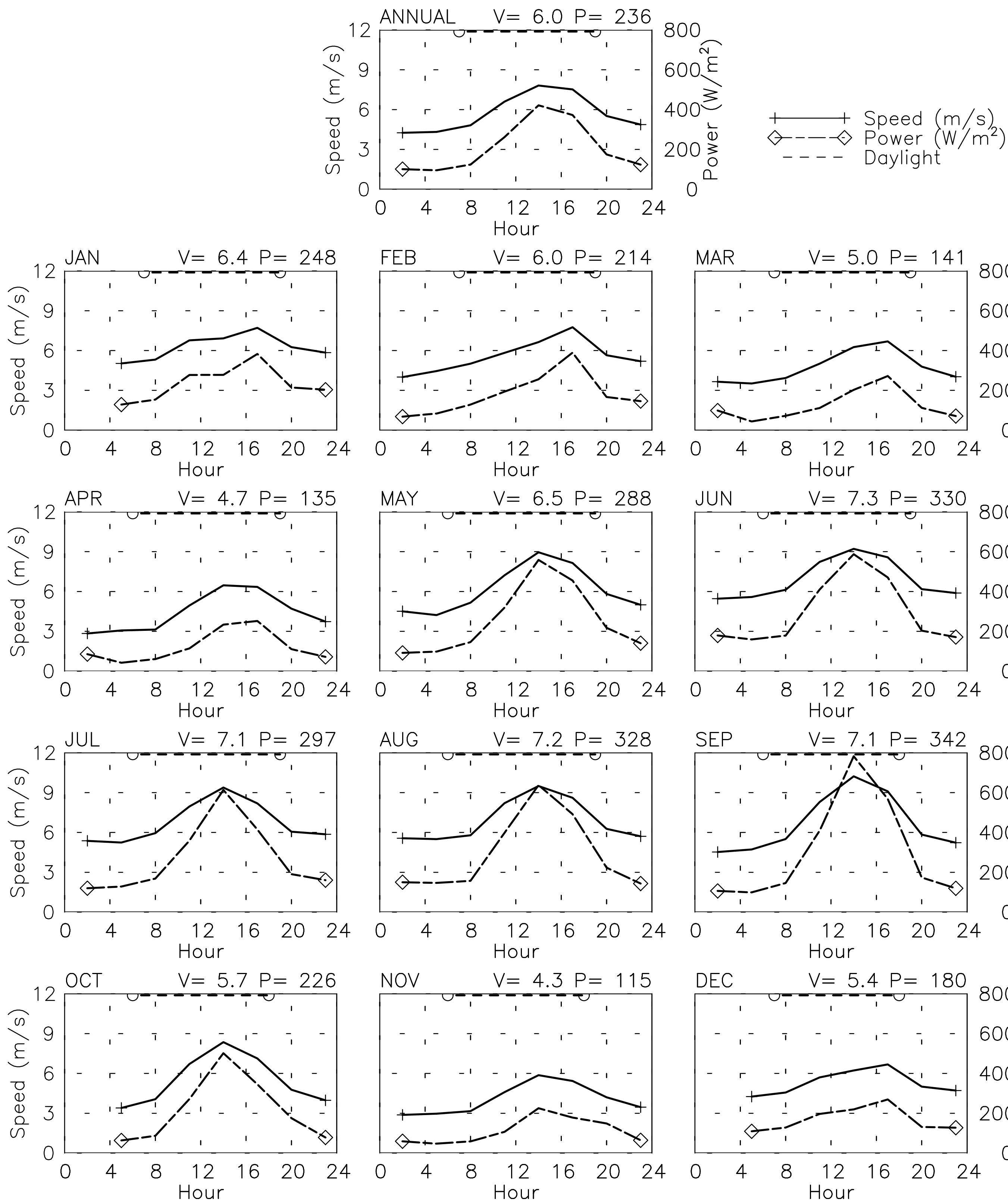
Mon Dec 9 12:33:49 2002

SPEED AND POWER BY HOUR

HAMBANTOTA CL – 434970

6° 07' N 81° 08' E – Elev 20m *LST=GMT +5 hours NT= +5

08/45–12/48 01/56–08/71 01/73–12/96



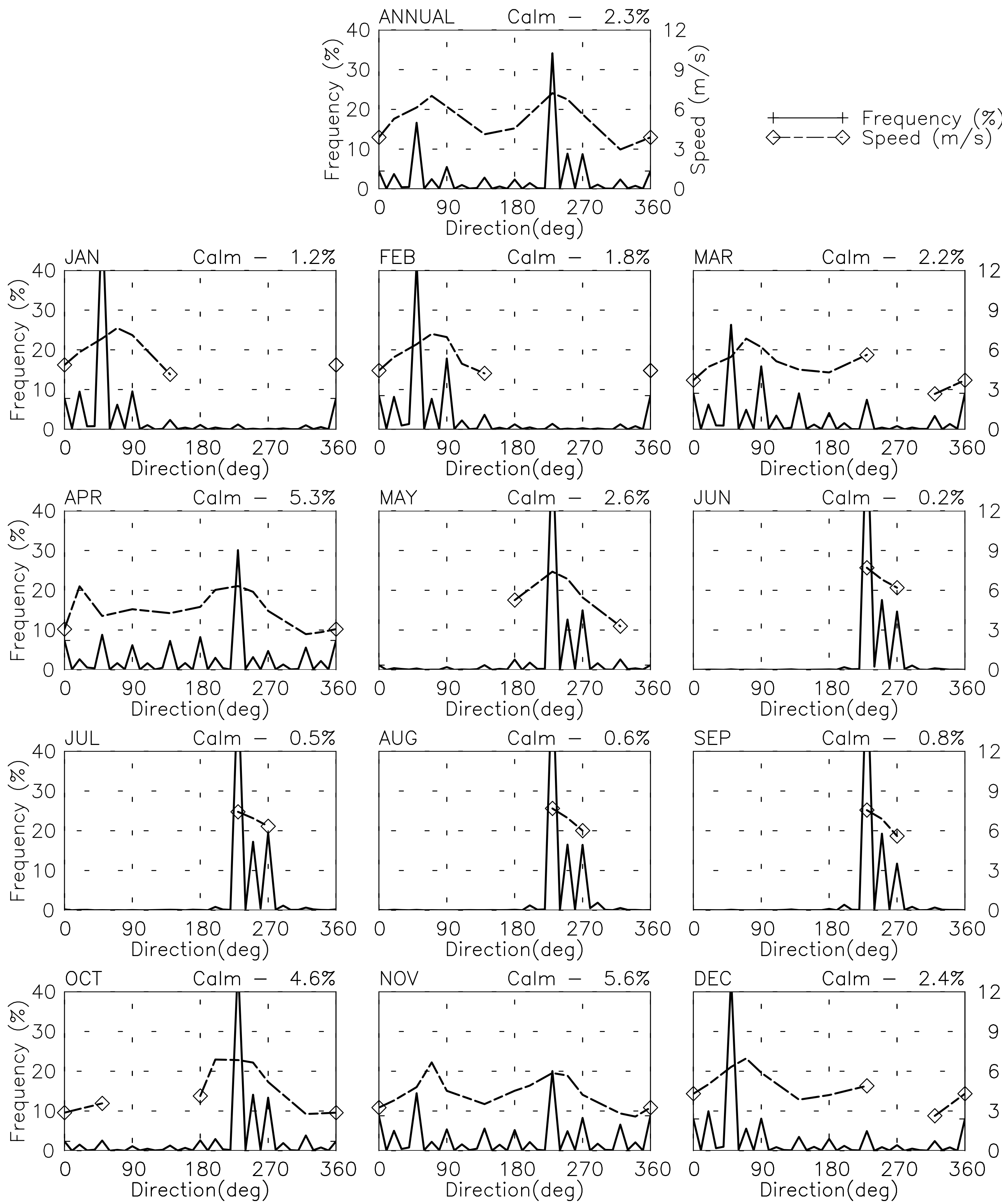
Mon Dec 9 12:19:18 2002

FREQUENCY AND SPEED BY DIRECTION

HAMBANTOTA CL – 434970

6° 07' N 81° 08' E – Elev 20m *LST=GMT +5 hours NT= +5

08/45–12/48 01/56–08/71 01/73–12/96



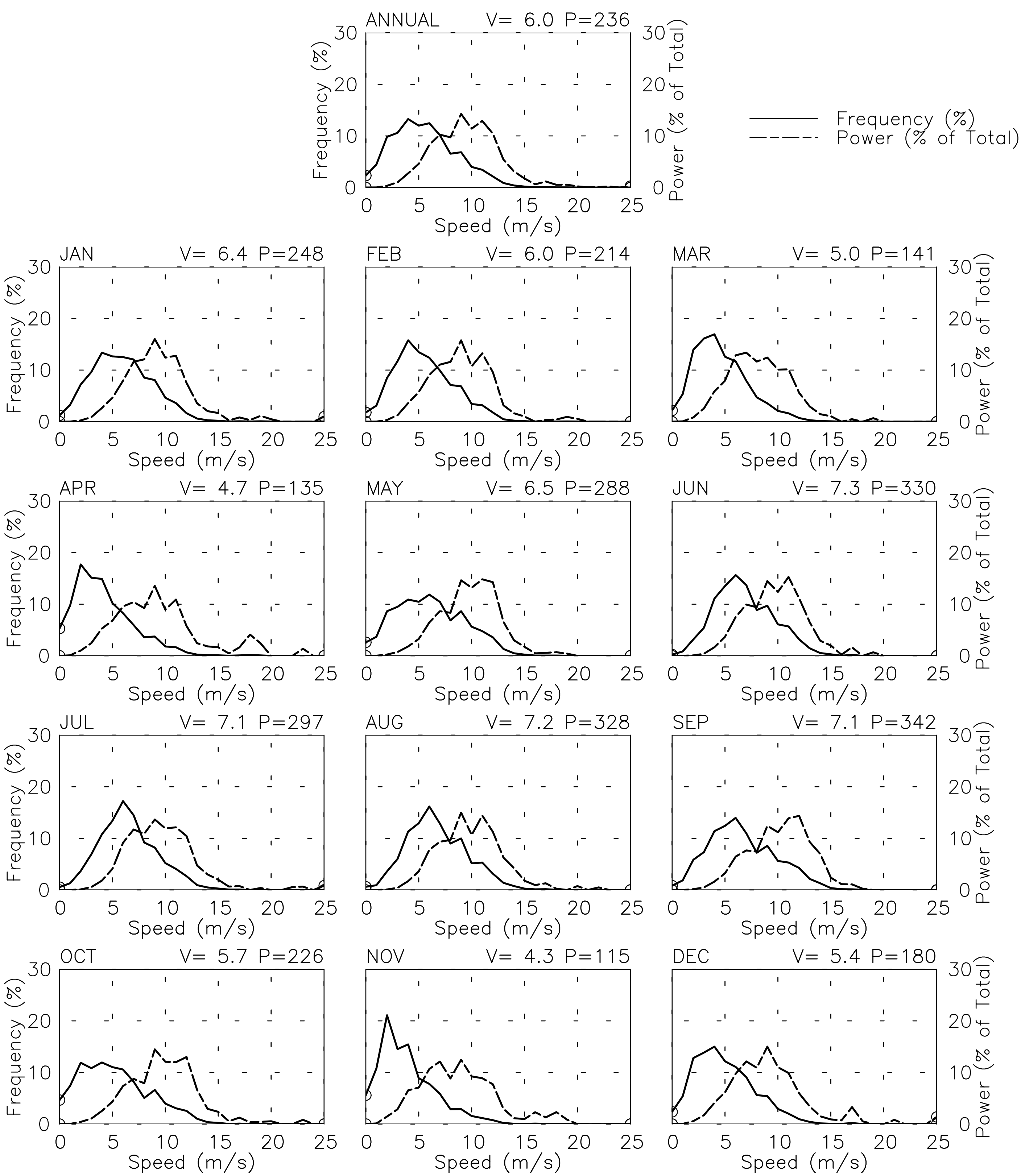
Mon Dec 9 12:33:53 2002

FREQUENCY OF SPEED & PERCENT OF POWER BY SPEED

HAMBANTOTA CL – 434970

6° 07' N 81° 08' E – Elev 20m *LST=GMT +5 hours NT= +5

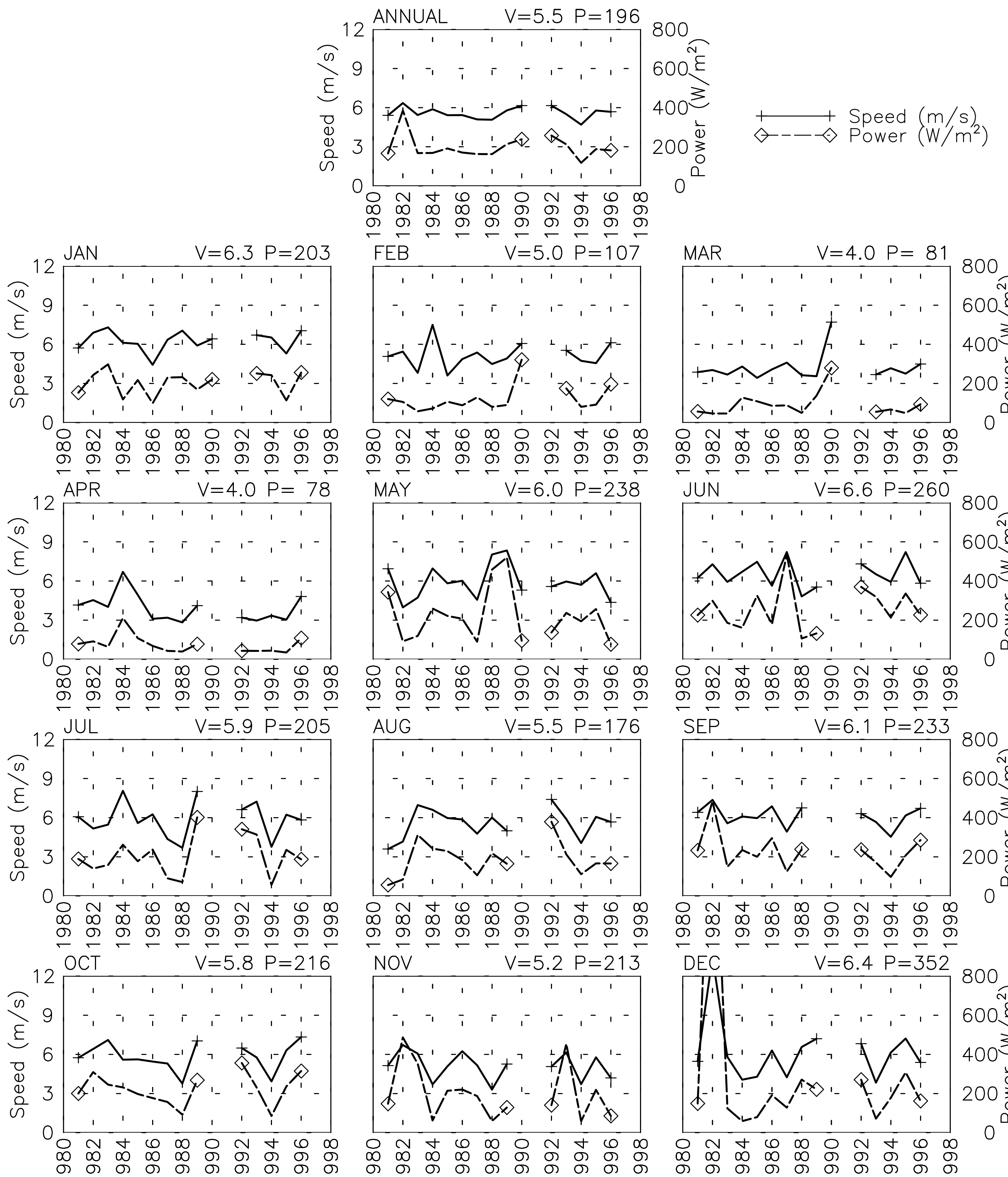
08/45–12/48 01/56–08/71 01/73–12/96



Mon Dec 9 12:33:54 2002

SPEED AND POWER BY YEAR

MALE INTL/HULULE ISMV – 435550
4° 12' N 73° 32' E – Elev 2m *LST=GMT +5 hours NT= +5
01/81–05/90 04/92–12/96



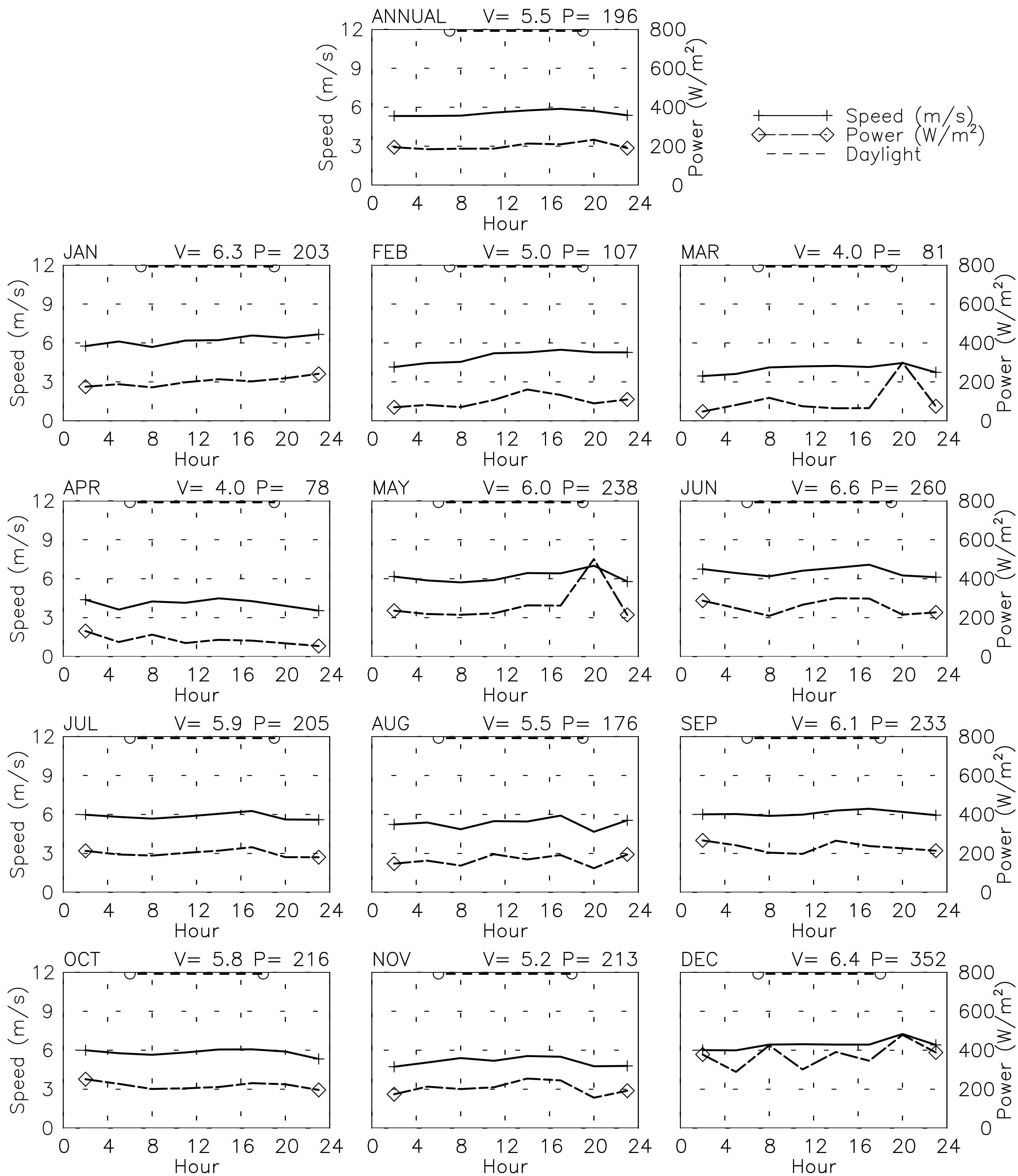
Wed Dec 4 12:07:05 2002

SPEED AND POWER BY HOUR

MALE INTL/HULULE ISMV – 435550

4° 12' N   73° 32' E – Elev   2m *LST=GMT +5 hours   NT= +5

01/81–05/90 04/92–12/96



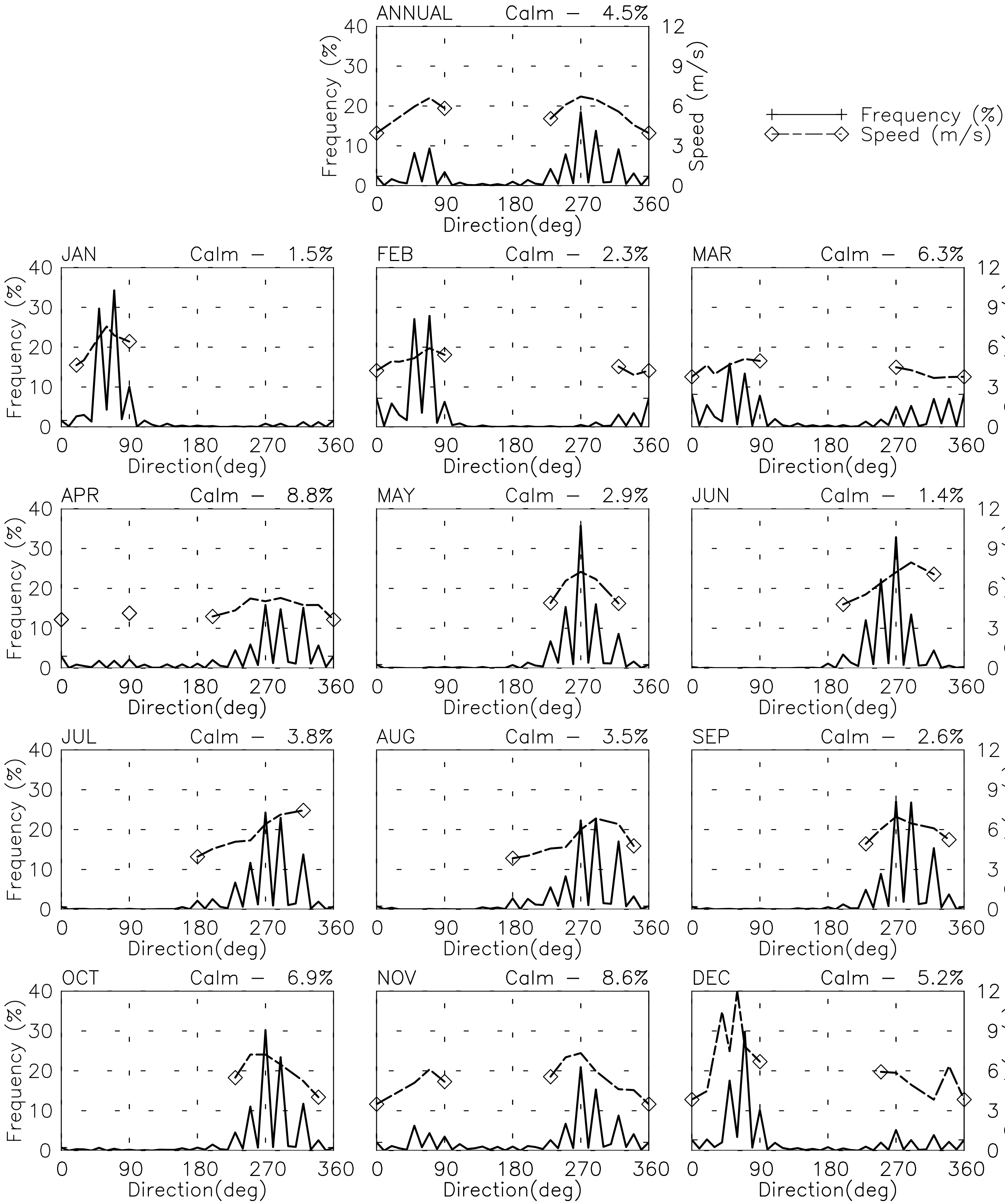
Wed Dec 4 12:07:07 2002

FREQUENCY AND SPEED BY DIRECTION

MALE INTL/HULULE ISMV – 435550

4° 12' N 73° 32' E – Elev 2m *LST=GMT +5 hours NT= +5

01/81–05/90 04/92–12/96



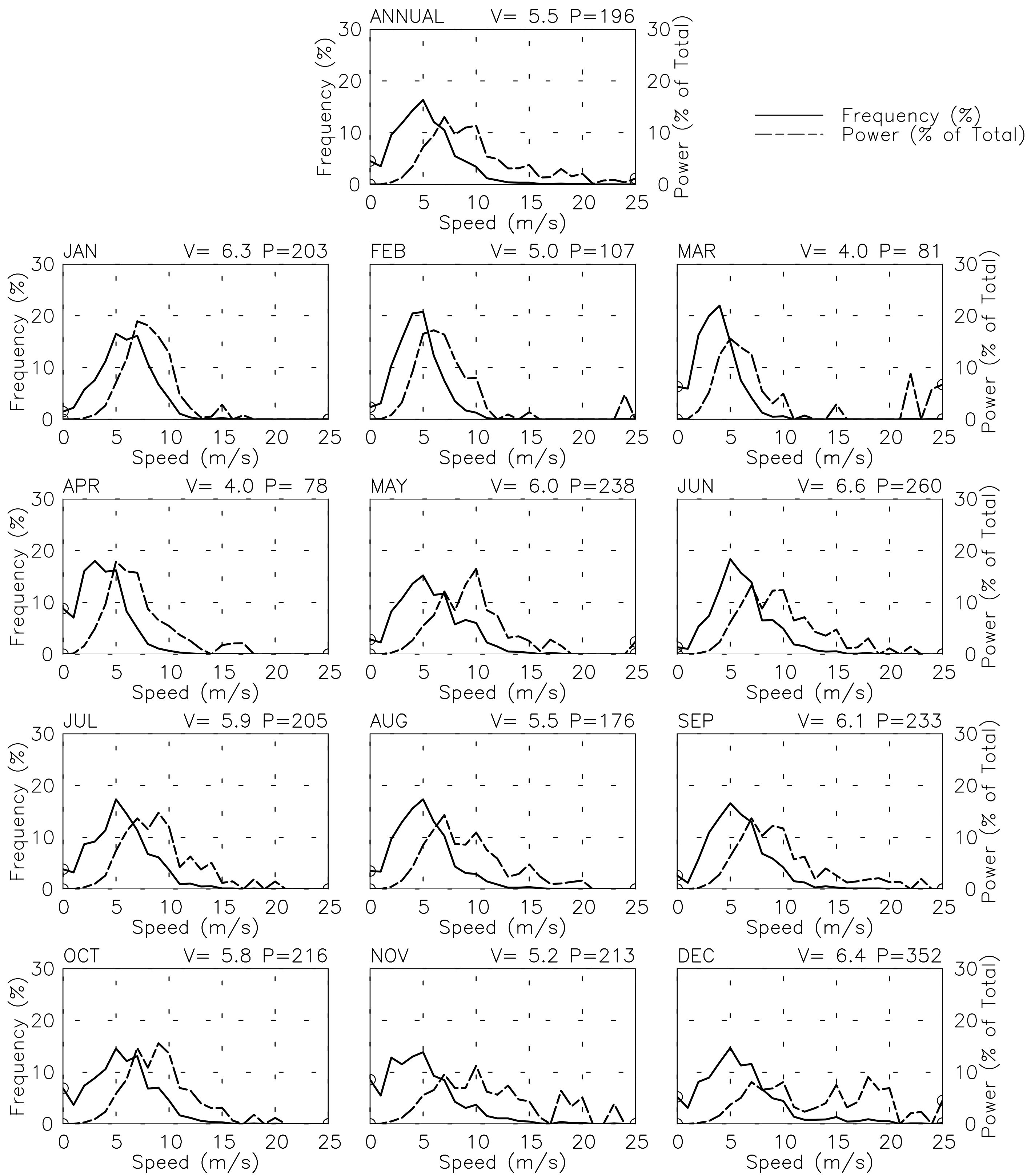
Wed Dec 4 12:07:07 2002

FREQUENCY OF SPEED & PERCENT OF POWER BY SPEED

MALE INTL/HULULE ISMV – 435550

4° 12' N   73° 32' E – Elev   2m   *LST=GMT +5 hours   NT= +5

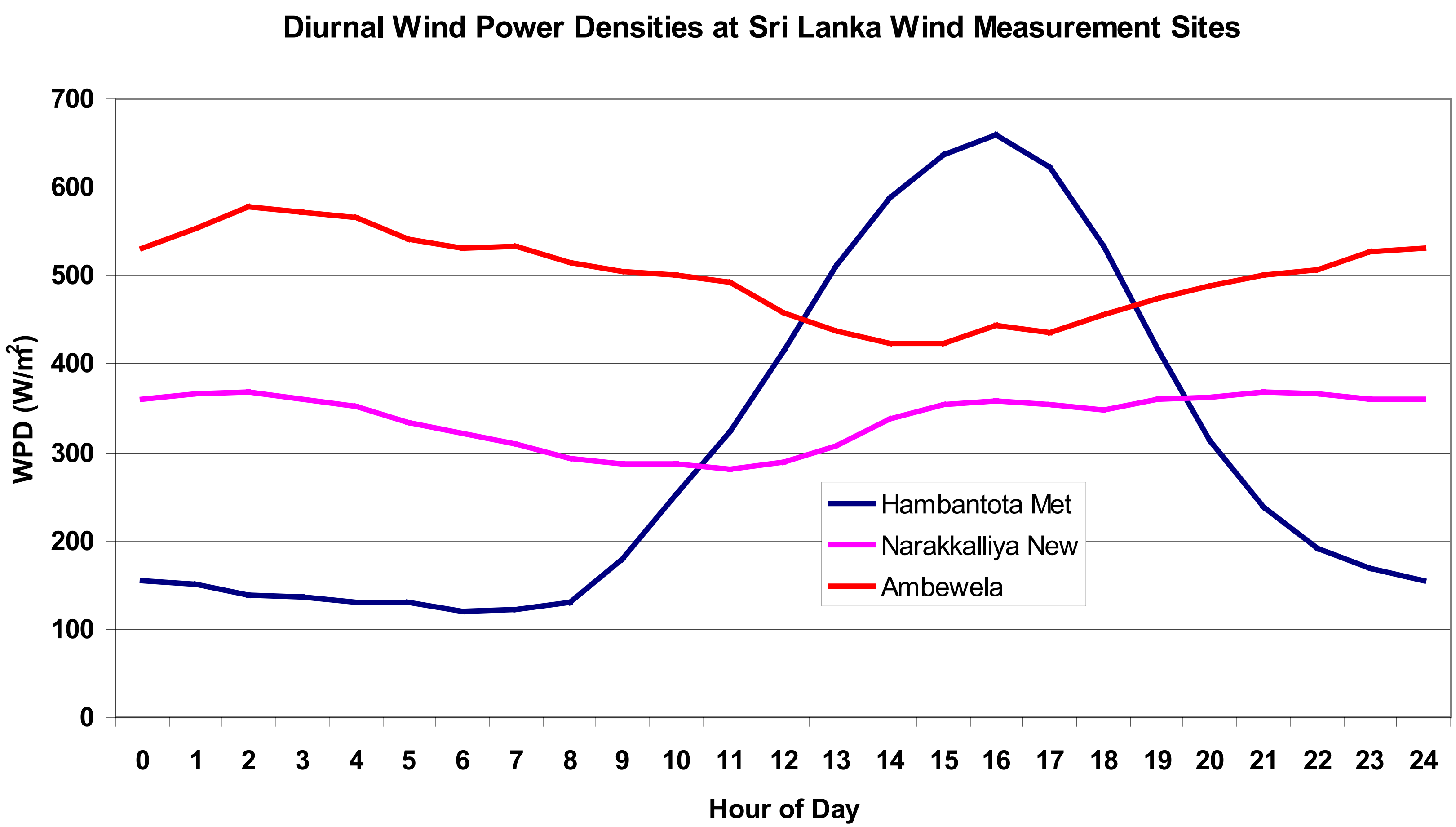
01/81–05/90 04/92–12/96



Wed Dec 4 12:07:08 2002

Appendix C:

Ceylon Electricity Board Wind Measurement Sites

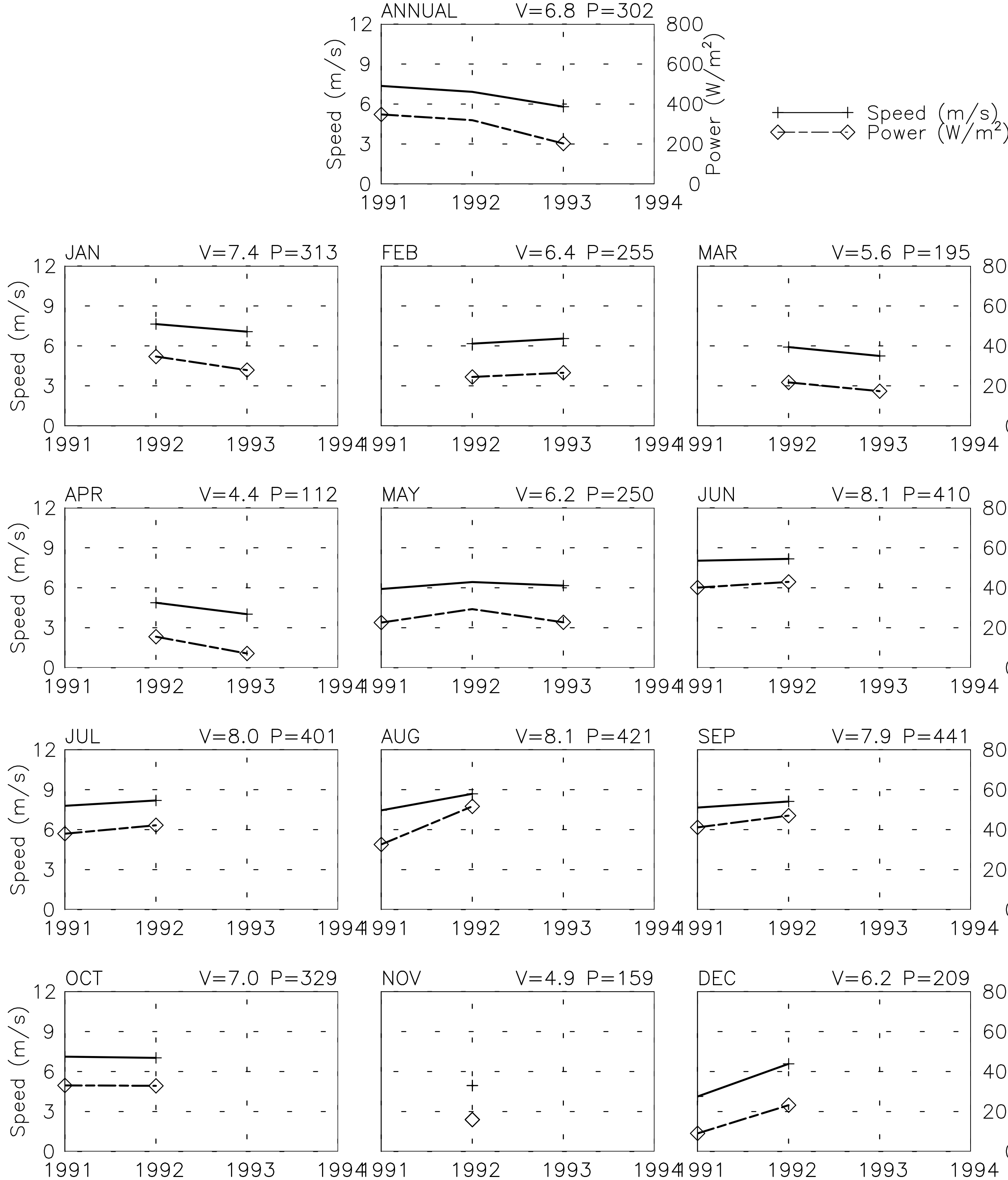

Diurnal Wind Power Densities at Sri Lanka Wind Measurement Sites
700
600
500
400
300
200
100
0
WPD (W/m2)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day
Hambantota Met
Narakkalliya New
Ambewela

SPEED AND POWER BY YEAR

Hmb Met. Stn DM 20m - 000003

6° 08' N 81° 08' E - Elev 15m LST=GMT+99 hours *NT= +5

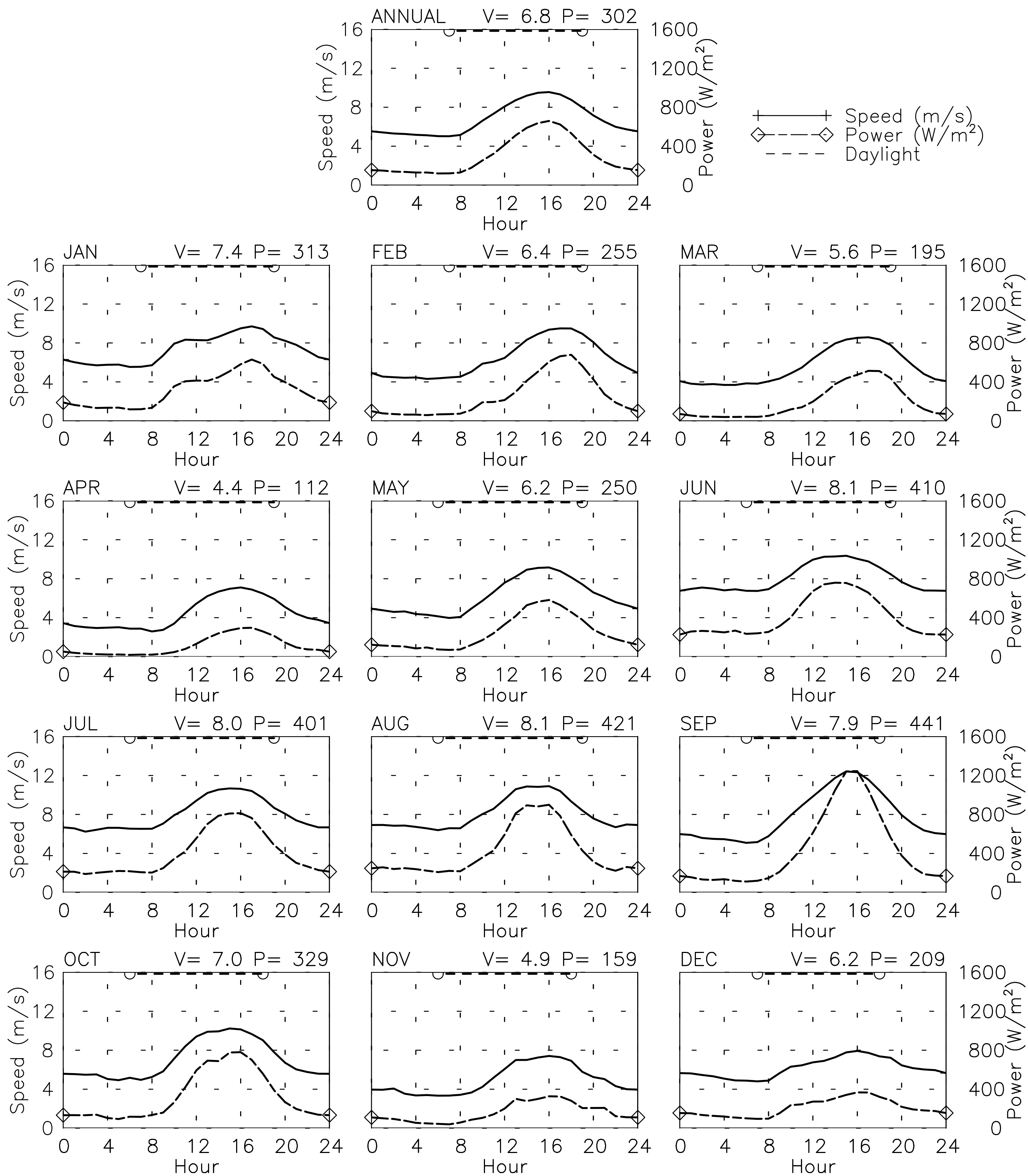
05/91-05/93



Tue Jun 24 12:12:56 2003

SPEED AND POWER BY HOUR

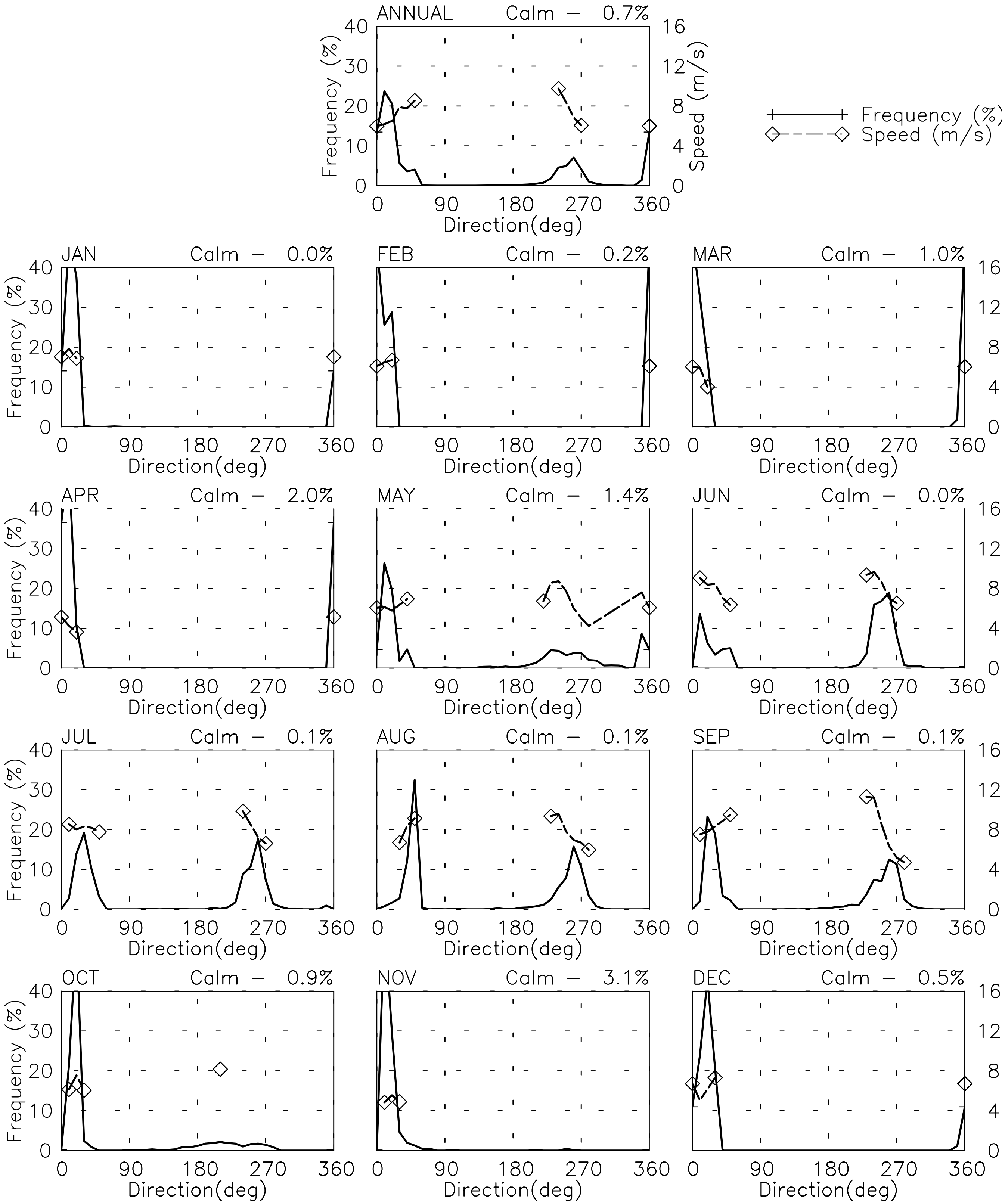
Hmb Met. Stn DM 20m – 000003
6° 08' N 81° 08' E – Elev 15m LST=GMT+99 hours *NT= +5
05/91–05/93



Tue Feb 4 11:56:59 2003

FREQUENCY AND SPEED BY DIRECTION

Hmb Met. Stn DM 20m – 000003
6° 08' N 81° 08' E – Elev 15m LST=GMT+99 hours *NT= +5
05/91–05/93



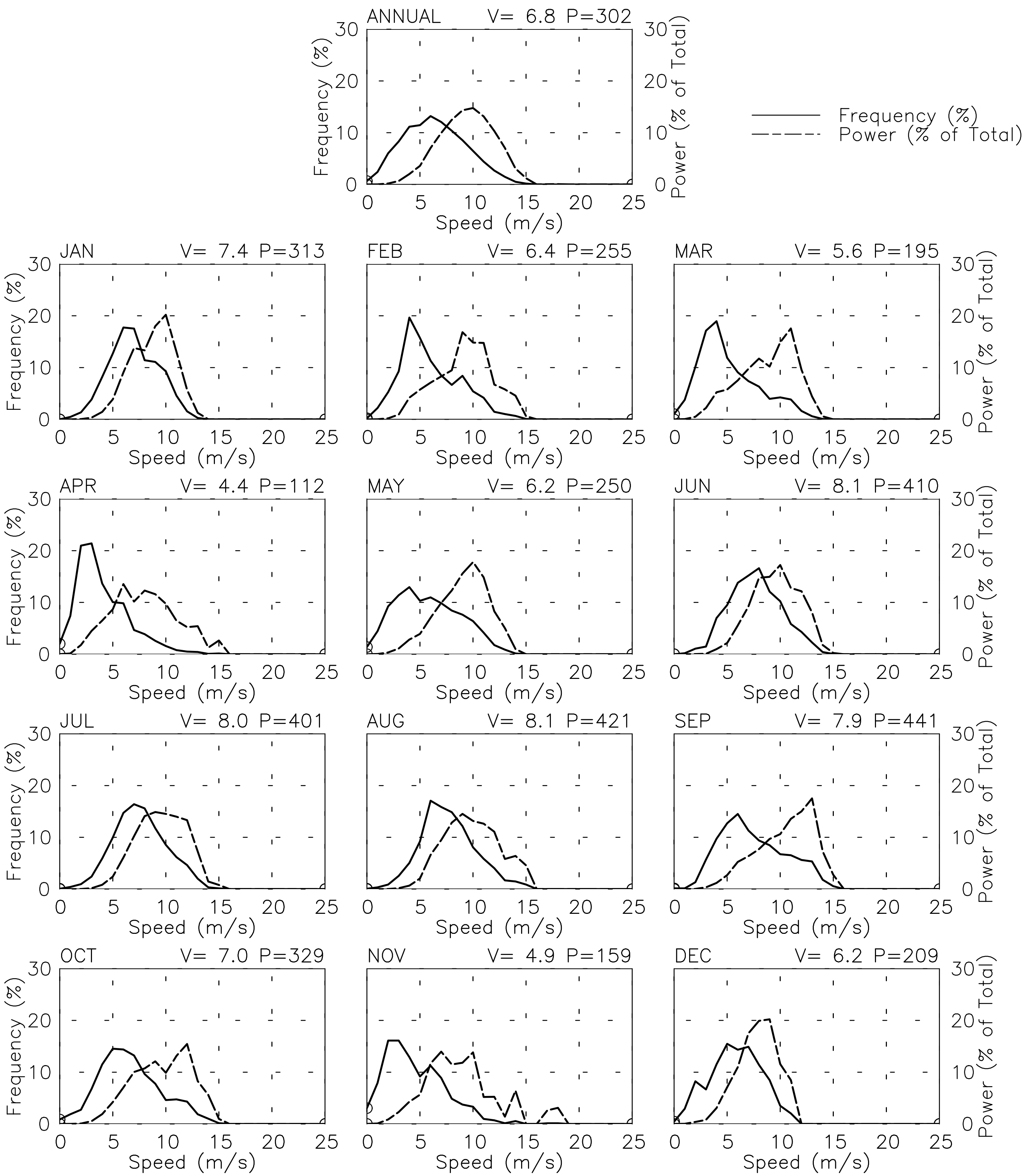
Tue Feb 4 11:57:00 2003

FREQUENCY OF SPEED & PERCENT OF POWER BY SPEED

Hmb Met. Stn DM 20m – 000003

6° 08' N 81° 08' E – Elev 15m LST=GMT+99 hours *NT= +5

05/91–05/93



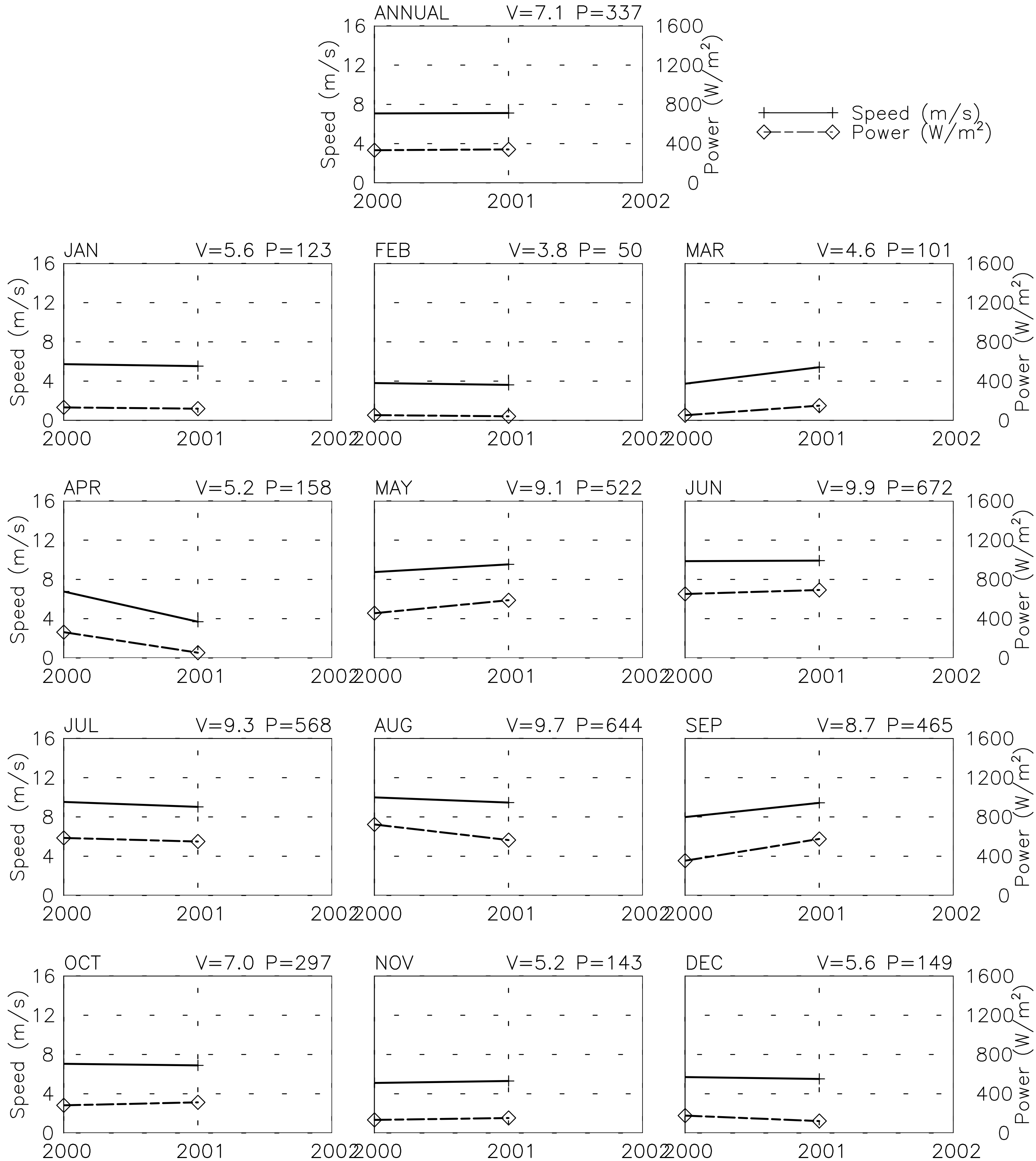
Tue Feb 4 11:57:01 2003

SPEED AND POWER BY YEAR

Narakkalliya New 40m – 000022

8° 01' N 79° 43' E – Elev 9999m LST=GMT+99 hours *NT= +5

01/00–12/01



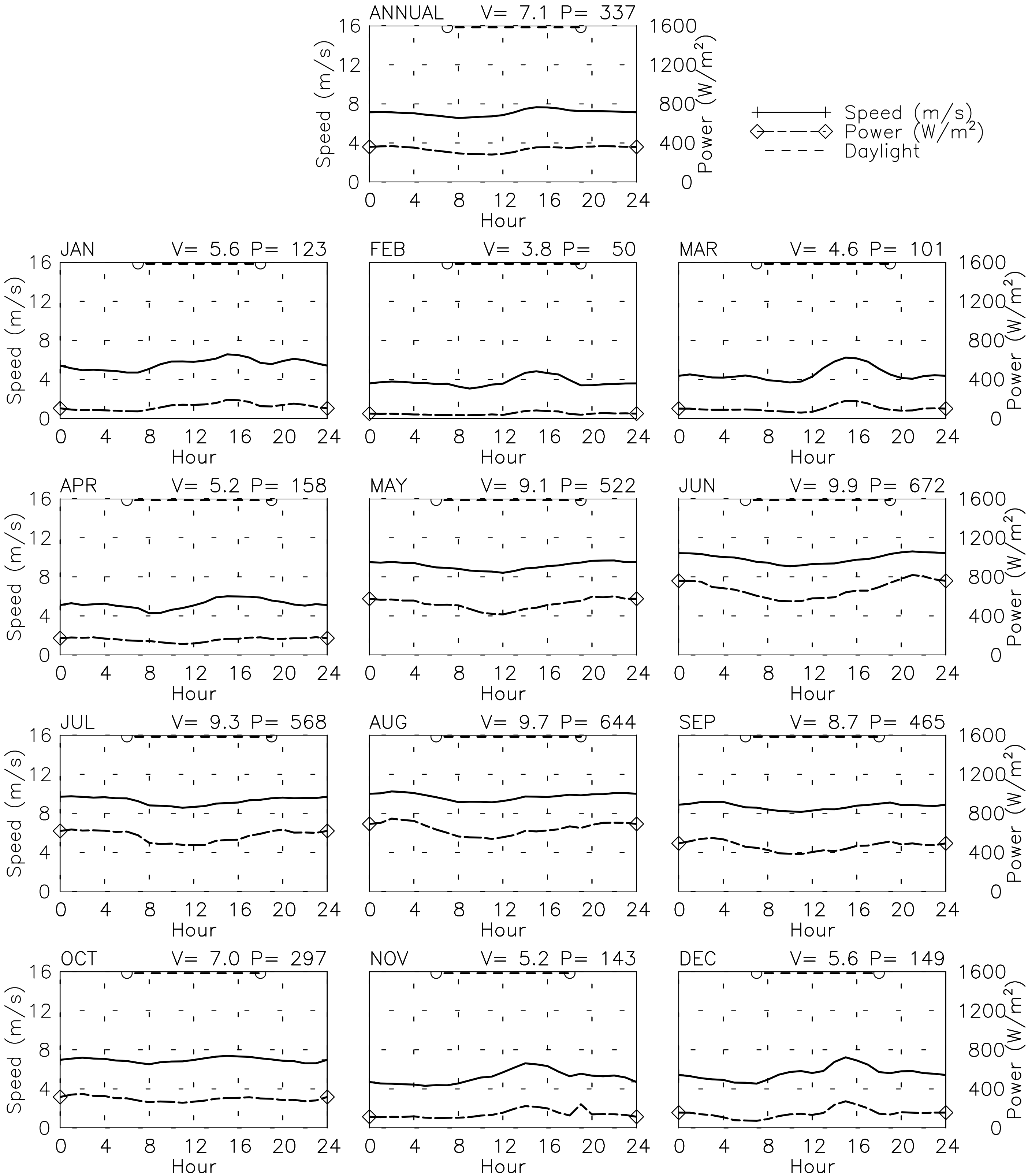
Tue Jun 24 13:35:51 2003

SPEED AND POWER BY HOUR

Narakkalliya New 40m – 000022

8° 01' N 79° 43' E – Elev 9999m LST=GMT+99 hours *NT= +5

01/00–12/01



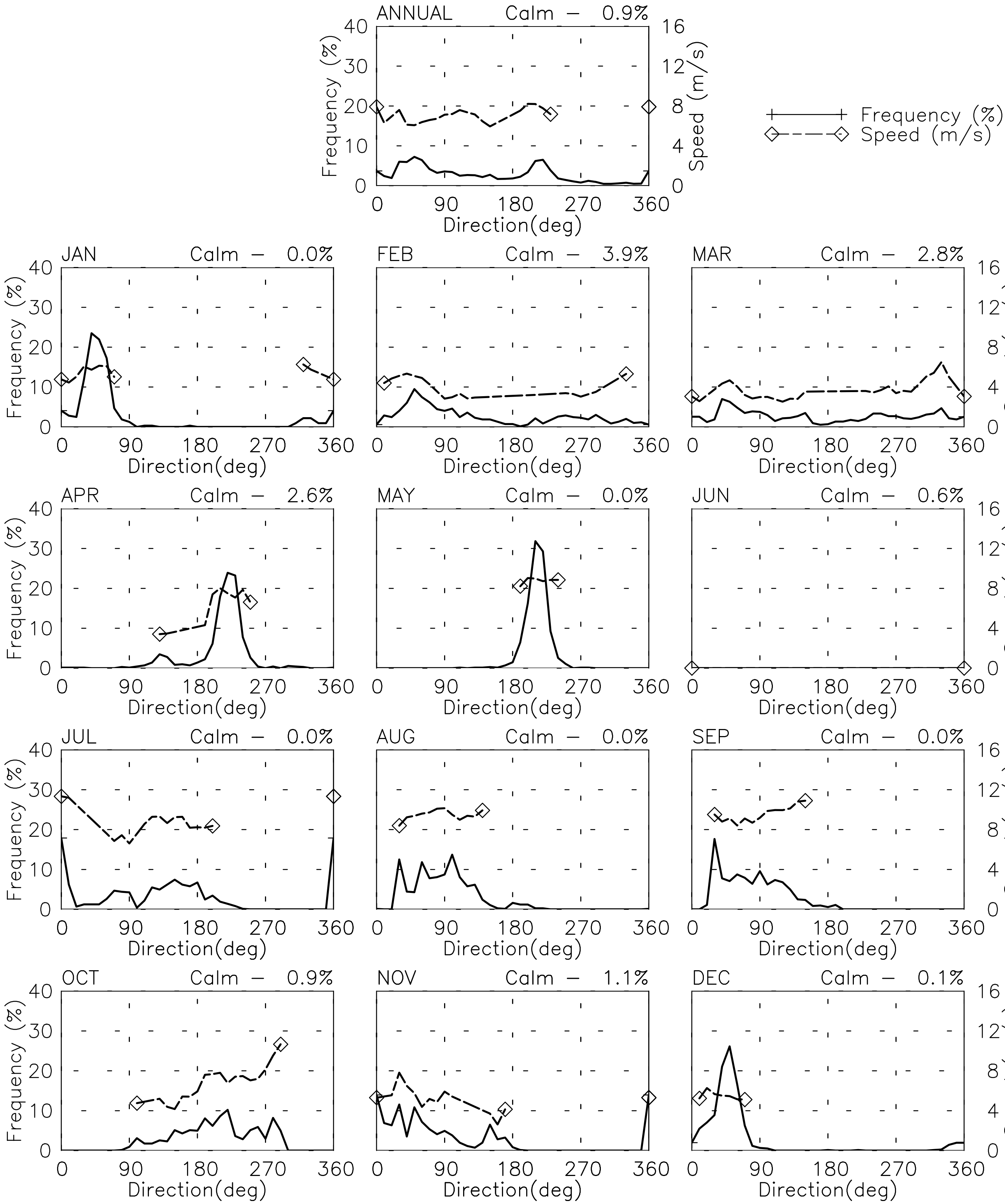
Tue Jun 24 13:35:52 2003

FREQUENCY AND SPEED BY DIRECTION

Narakkalliya New 40m – 000022

8° 01' N 79° 43' E – Elev 9999m LST=GMT+99 hours *NT= +5

01/00–12/01



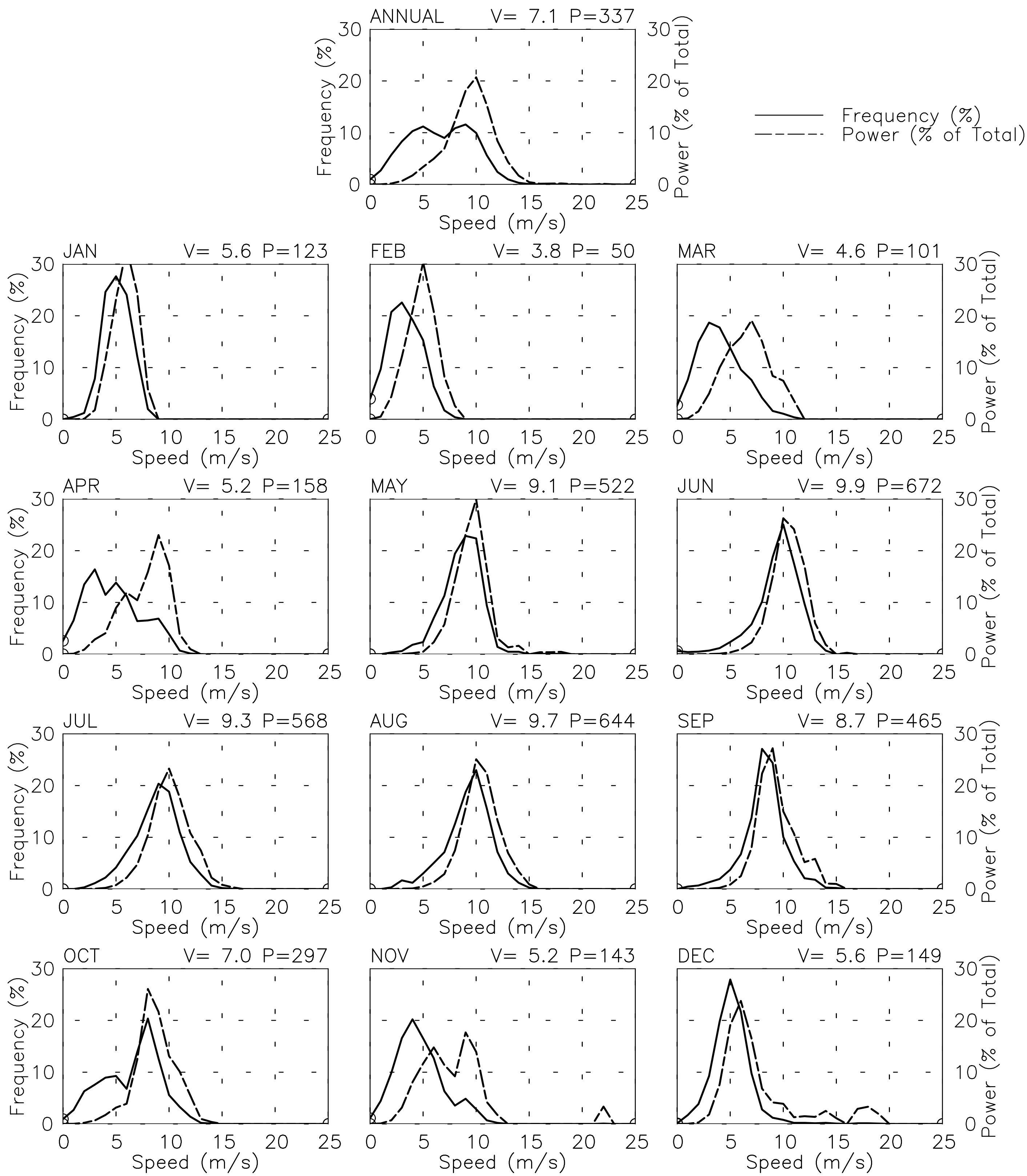
Tue Jun 24 13:35:53 2003

FREQUENCY OF SPEED & PERCENT OF POWER BY SPEED

Narakkalliya New 40m – 000022

8° 01' N 79° 43' E – Elev 9999m LST=GMT+99 hours *NT= +5

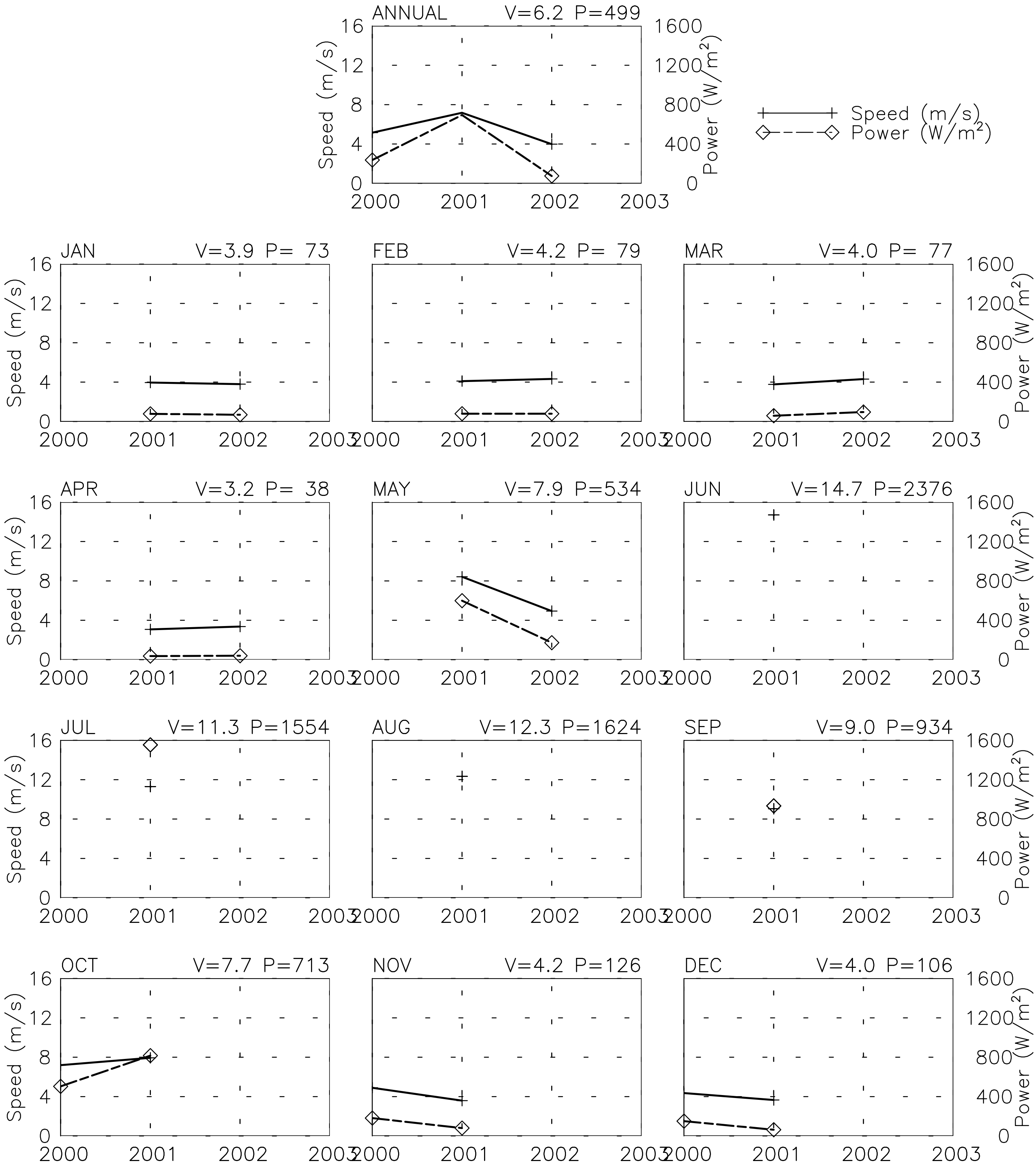
01/00–12/01



Tue Jun 24 13:35:53 2003

SPEED AND POWER BY YEAR

Ambewela 40m – 000028
6° 54' N 80° 49' E – Elev 9999m LST=GMT+99 hours *NT= +5
10/00–05/02



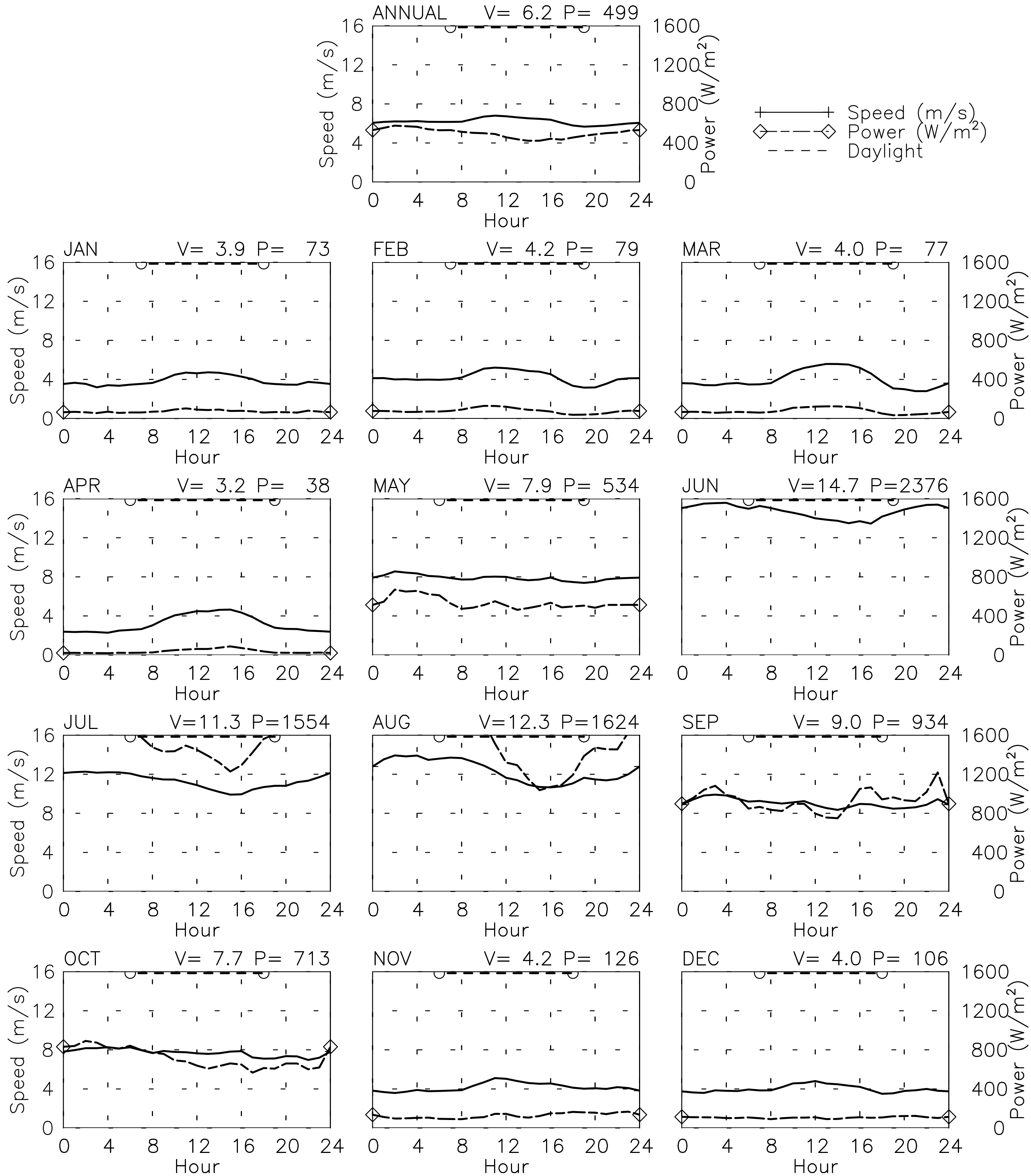
Tue Jun 24 13:35:56 2003

SPEED AND POWER BY HOUR

Ambewela 40m − 000028

6° 54' N 80° 49' E − Elev 9999m LST=GMT+99 hours *NT= +5

10/00−05/02



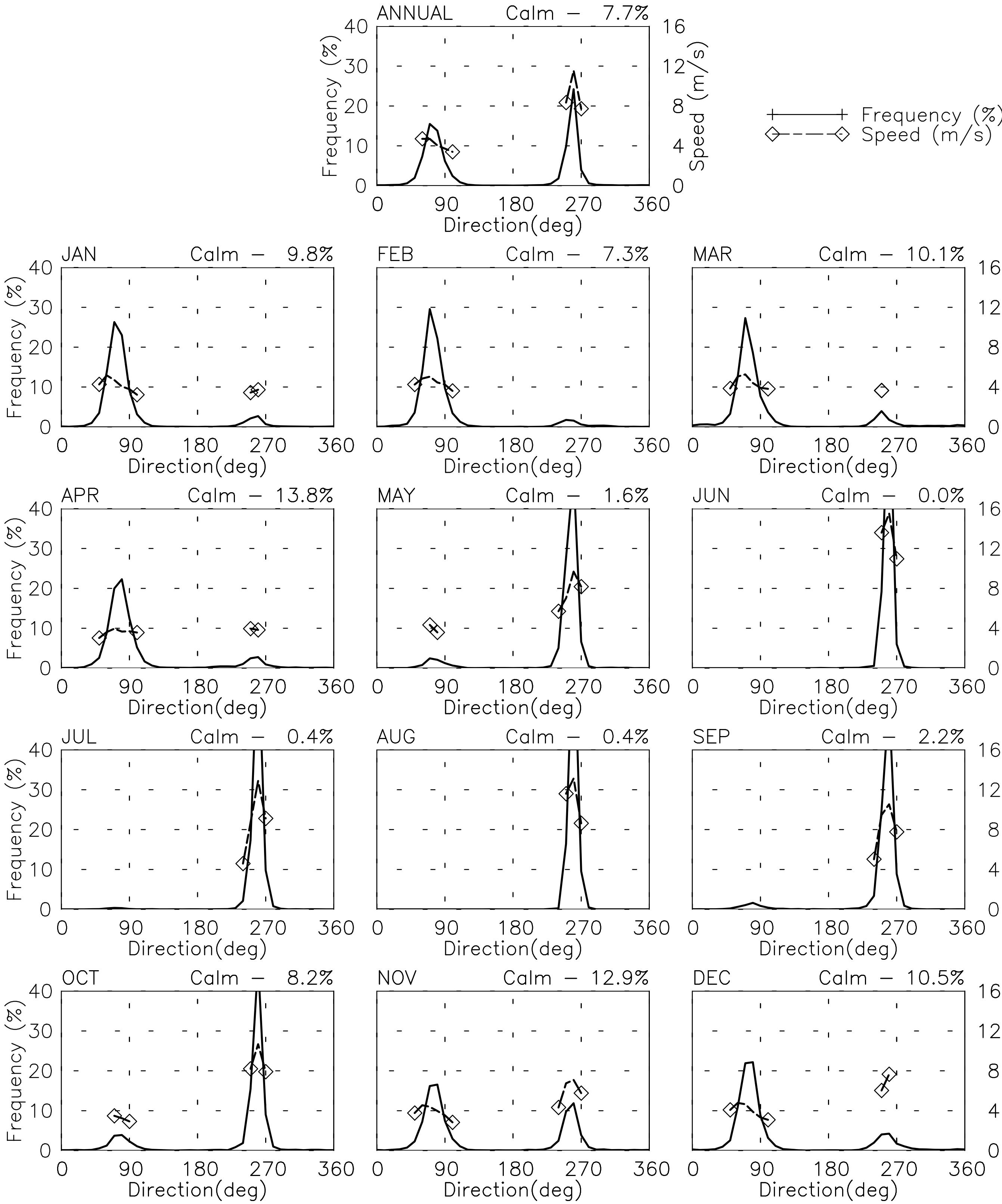
Tue Jun 24 13:35:56 2003

FREQUENCY AND SPEED BY DIRECTION

Ambewela 40m – 000028

6° 54' N 80° 49' E – Elev 9999m LST=GMT+99 hours *NT= +5

10/00–05/02



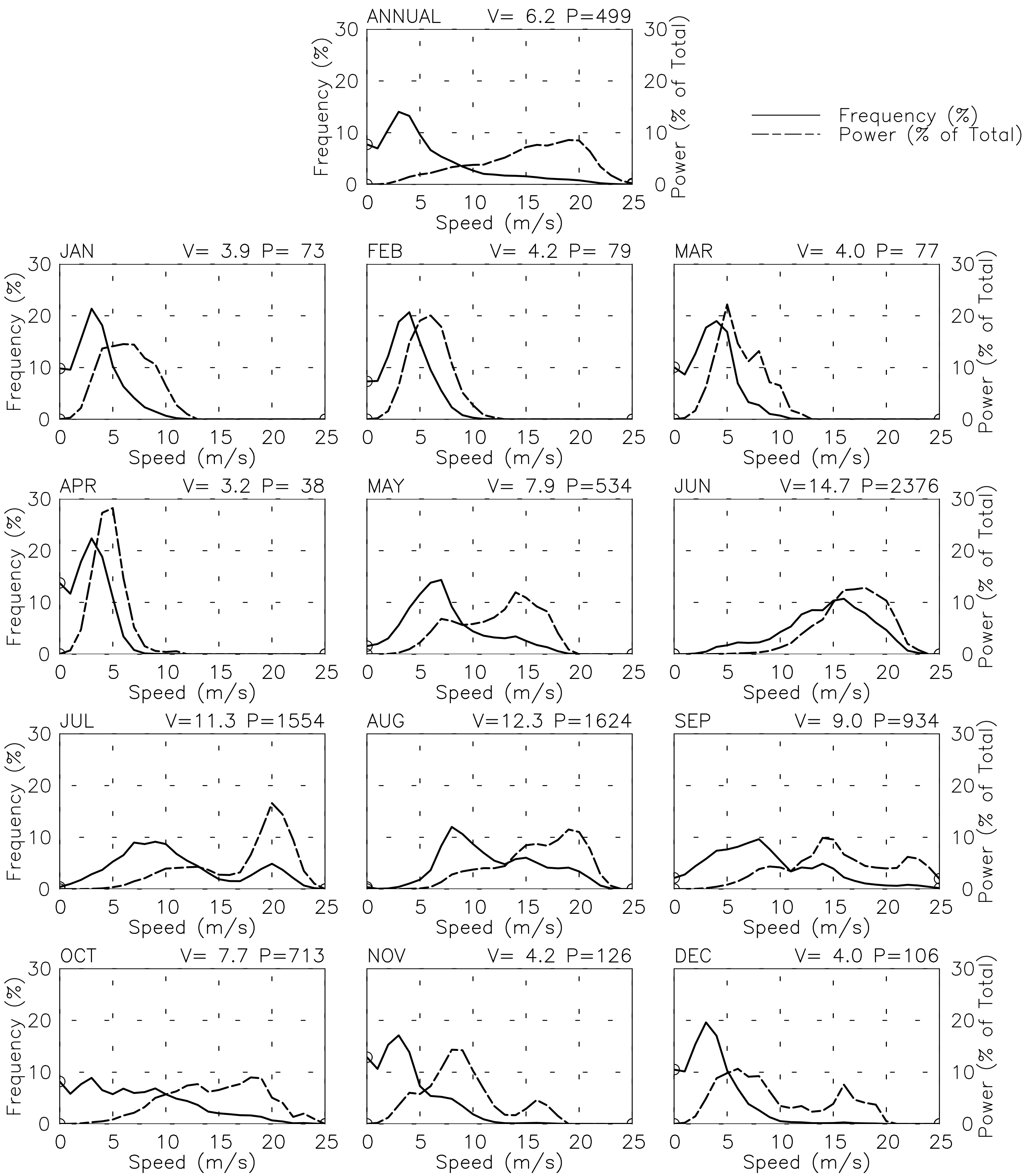
Tue Jun 24 13:35:57 2003

FREQUENCY OF SPEED & PERCENT OF POWER BY SPEED

Ambewela 40m - 000028

6° 54' N 80° 49' E - Elev 9999m LST=GMT+99 hours *NT= +5

10/00-05/02



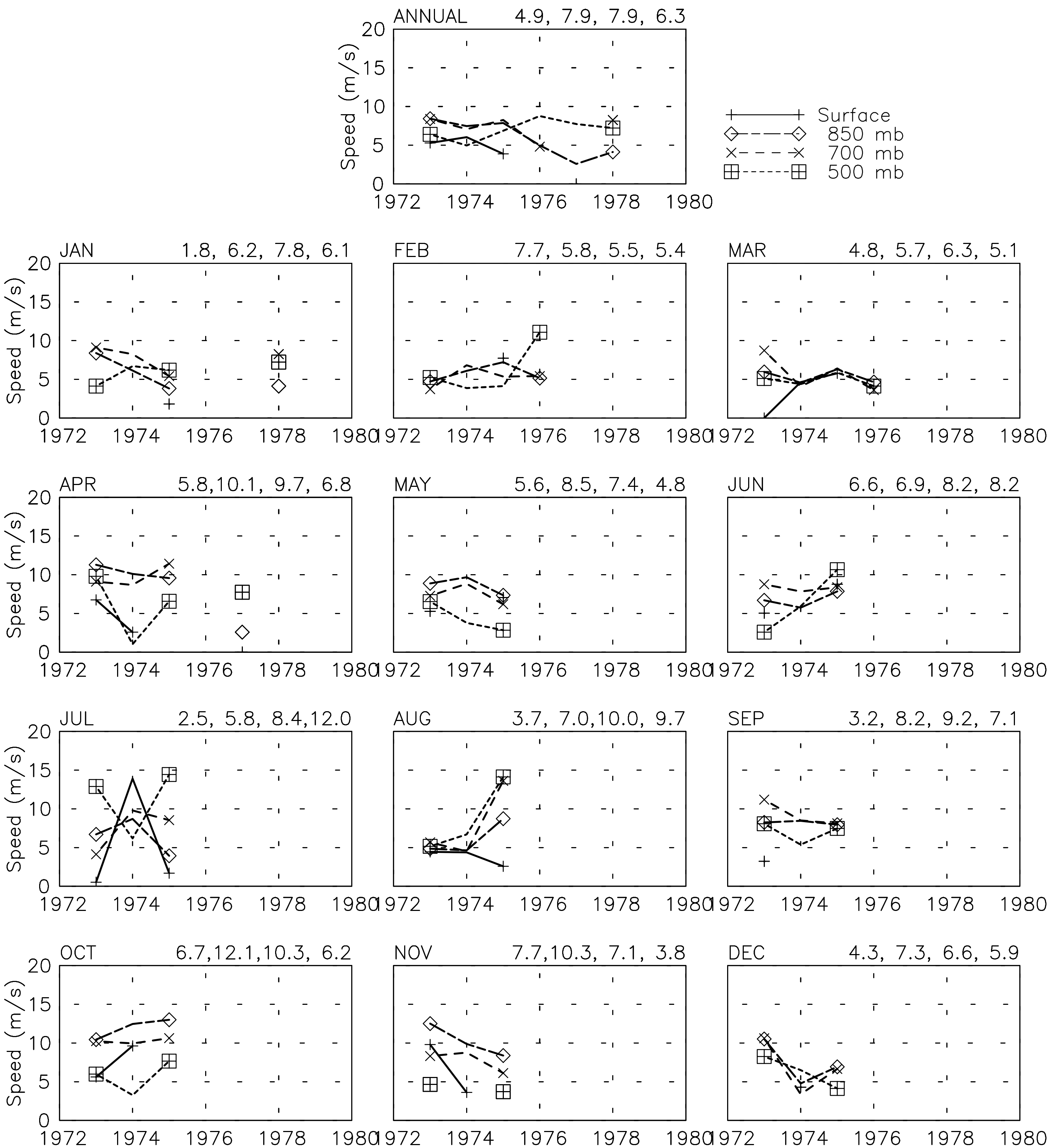
Tue Jun 24 13:35:58 2003

Appendix D:

Upper Air Meteorological Stations

SPEED BY PRESSURE LEVEL & YEAR

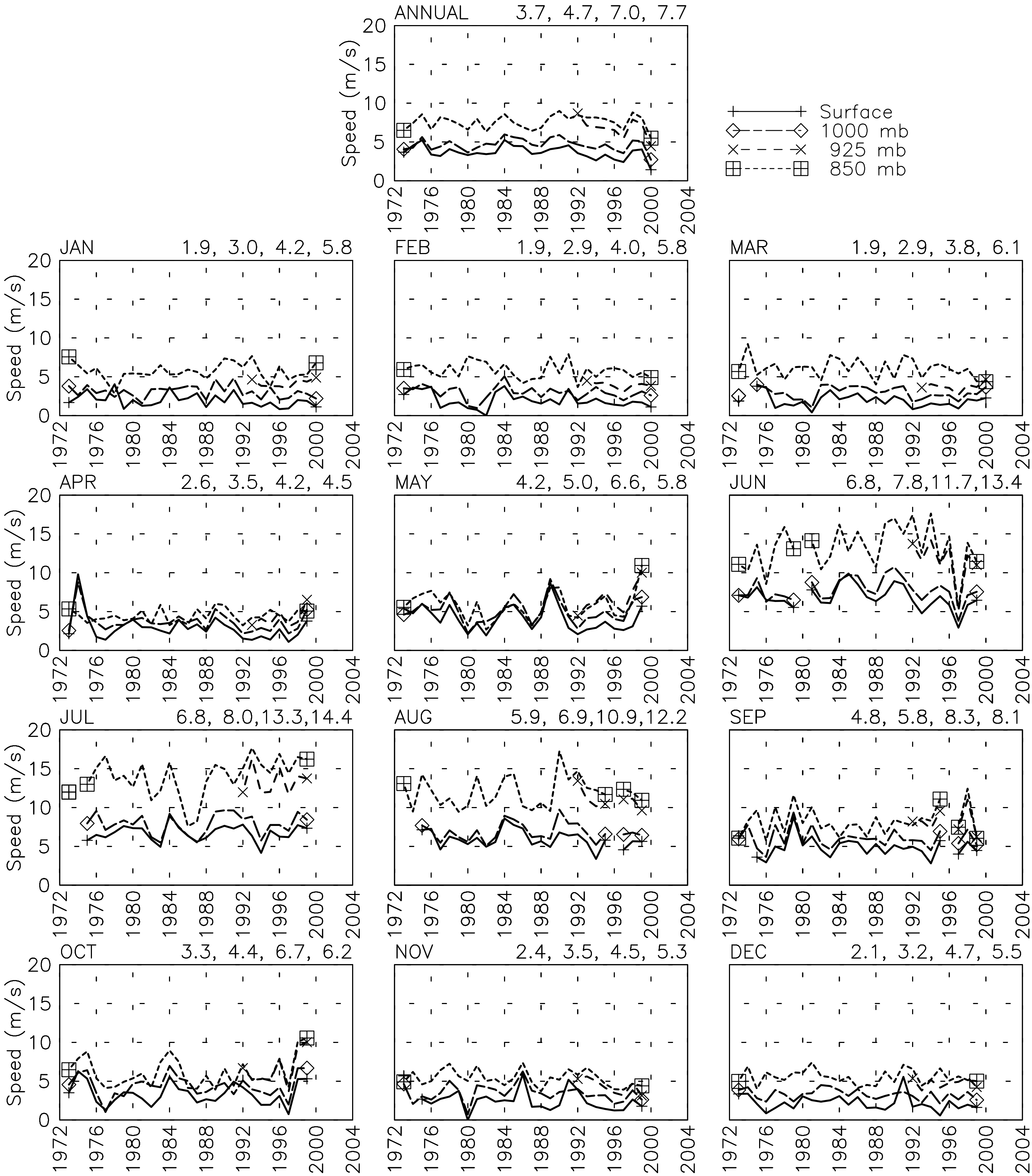
Gan Island – 41350 – 0500 LST
0° 41' S 73° 09' E – Elev 2m
01/73–01/78



Thu Jun 26 12:32:40 2003

SPEED BY PRESSURE LEVEL & YEAR

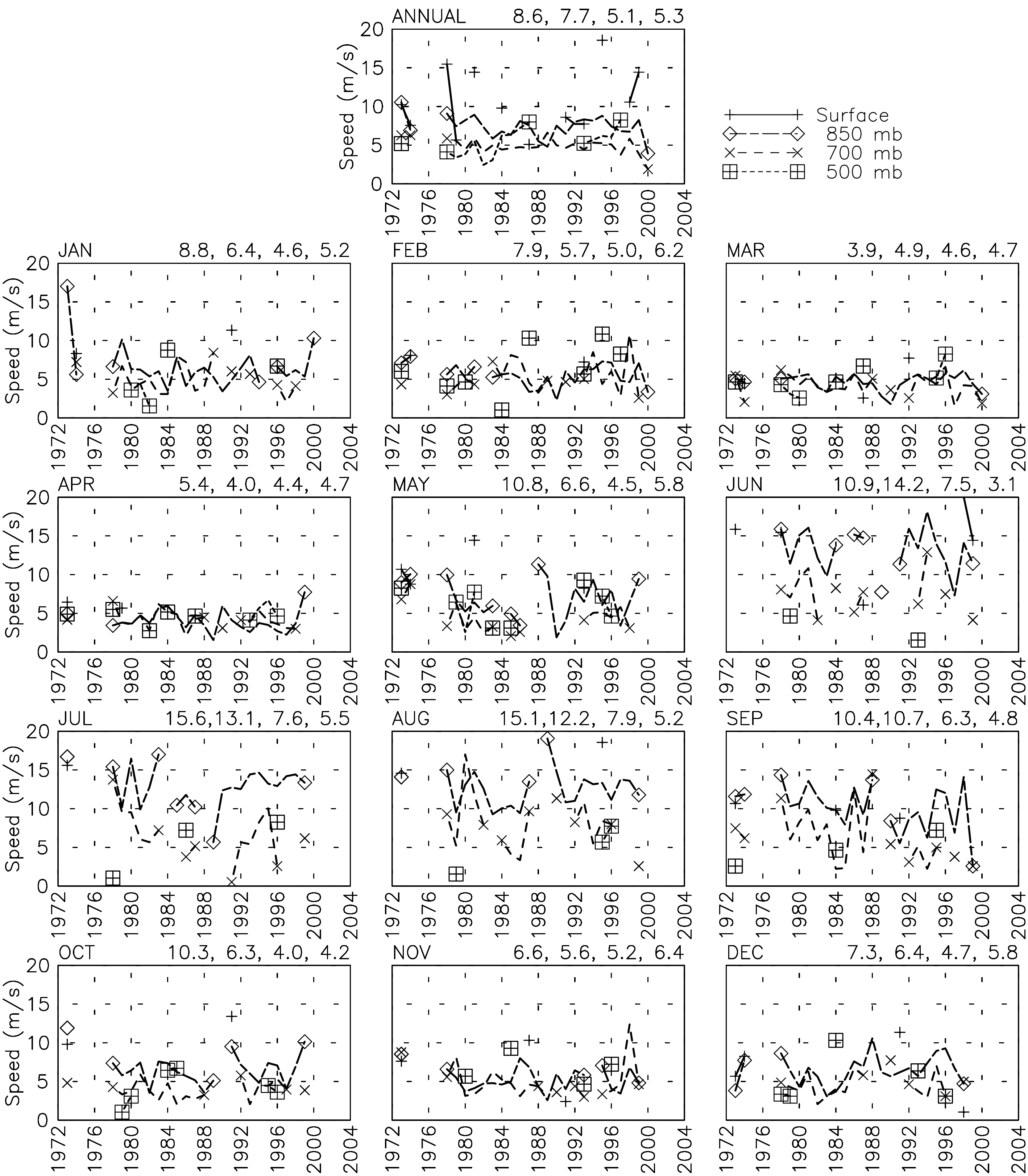
Minicoy Island – 43369 – 0500 LST
8° 18' N 73° 09' E – Elev 1m
01/73–03/00



Thu Jun 26 12:22:16 2003

SPEED BY PRESSURE LEVEL & YEAR

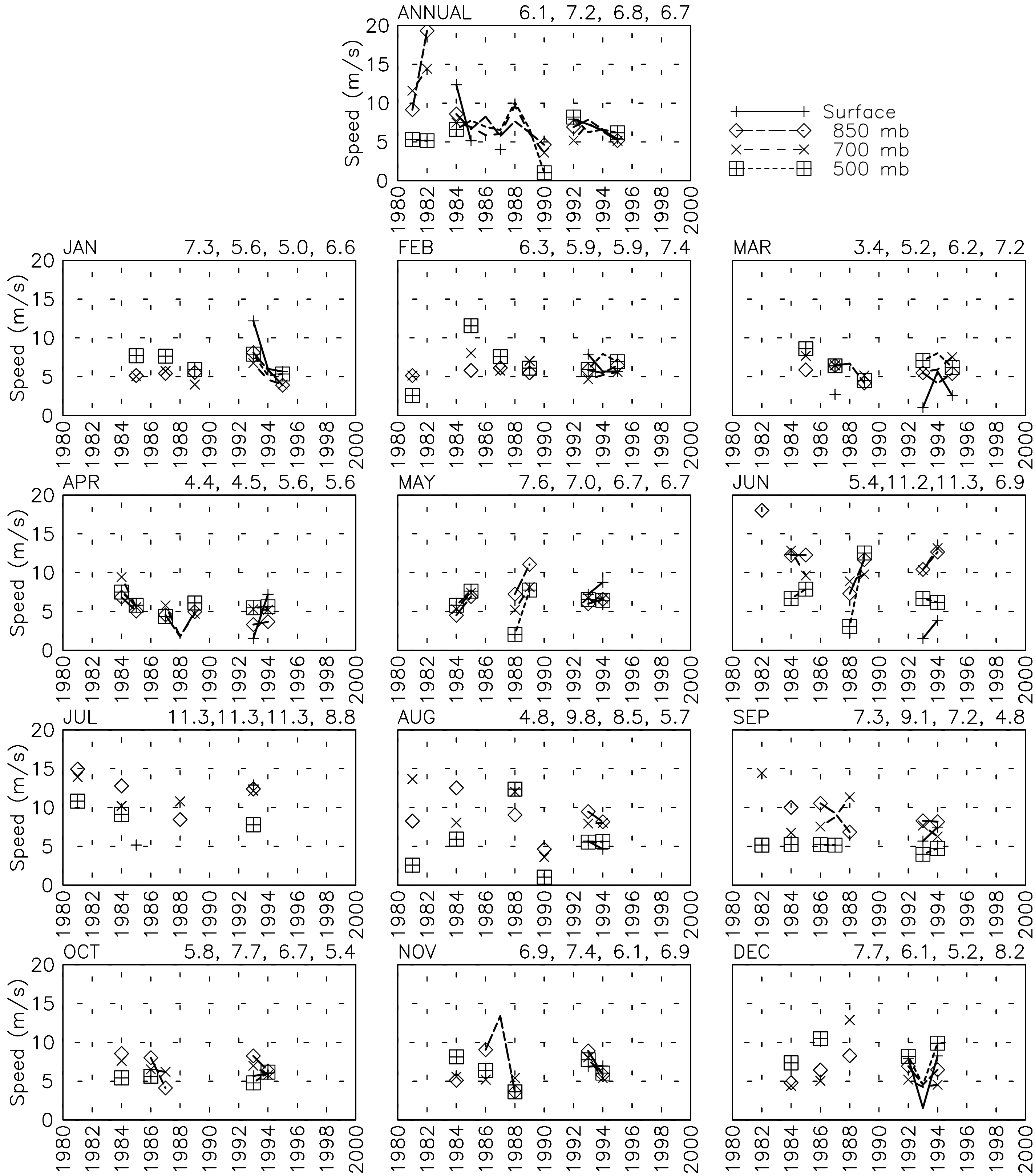
Hambantota – 43497 – 0500 LST
6° 07' N 81° 08' E – Elev 18m
01/73–03/00



Thu Jun 26 12:25:03 2003

SPEED BY PRESSURE LEVEL & YEAR

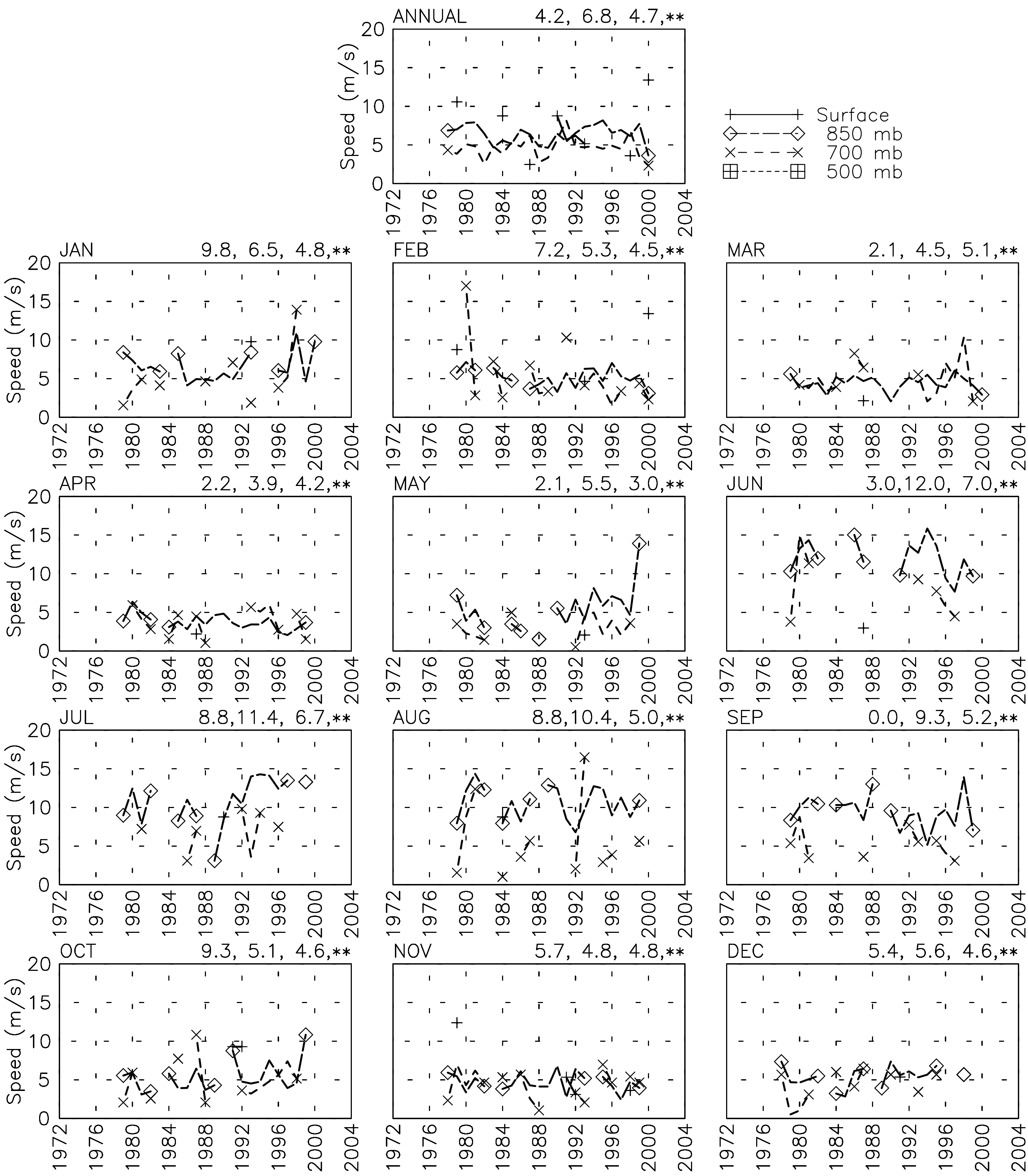
Male – 43555 – 0500 LST
4° 12' N 73° 12' E – Elev 6m
01/81–07/99



Thu Jun 26 12:25:18 2003

SPEED BY PRESSURE LEVEL & YEAR

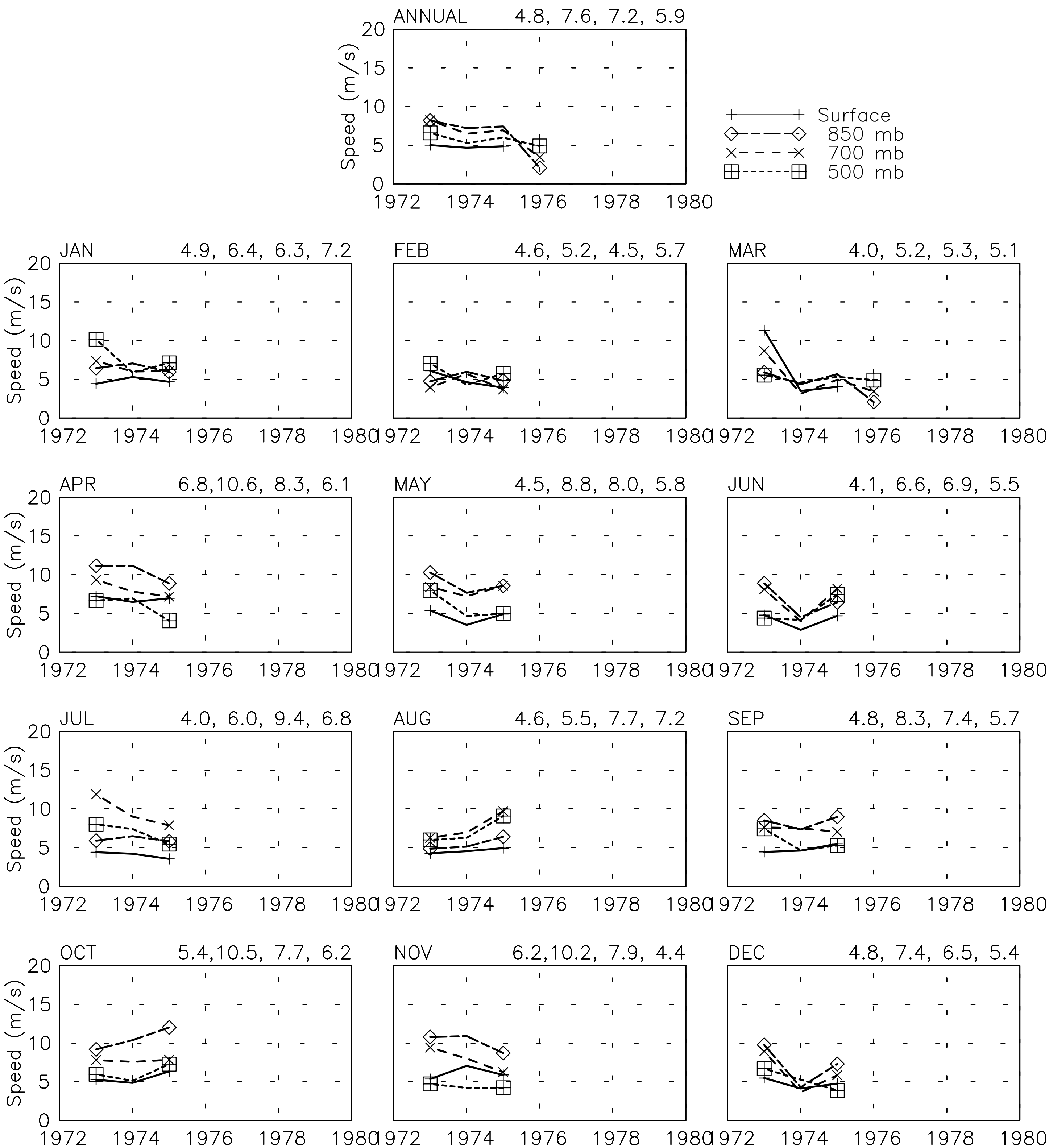
Hambantota – 43497 – 1100 LST
6d 07' N   81d 08' E – Elev   18m
01/73–03/00



Thu Jun 26 12:25:06 2003

SPEED BY PRESSURE LEVEL & YEAR

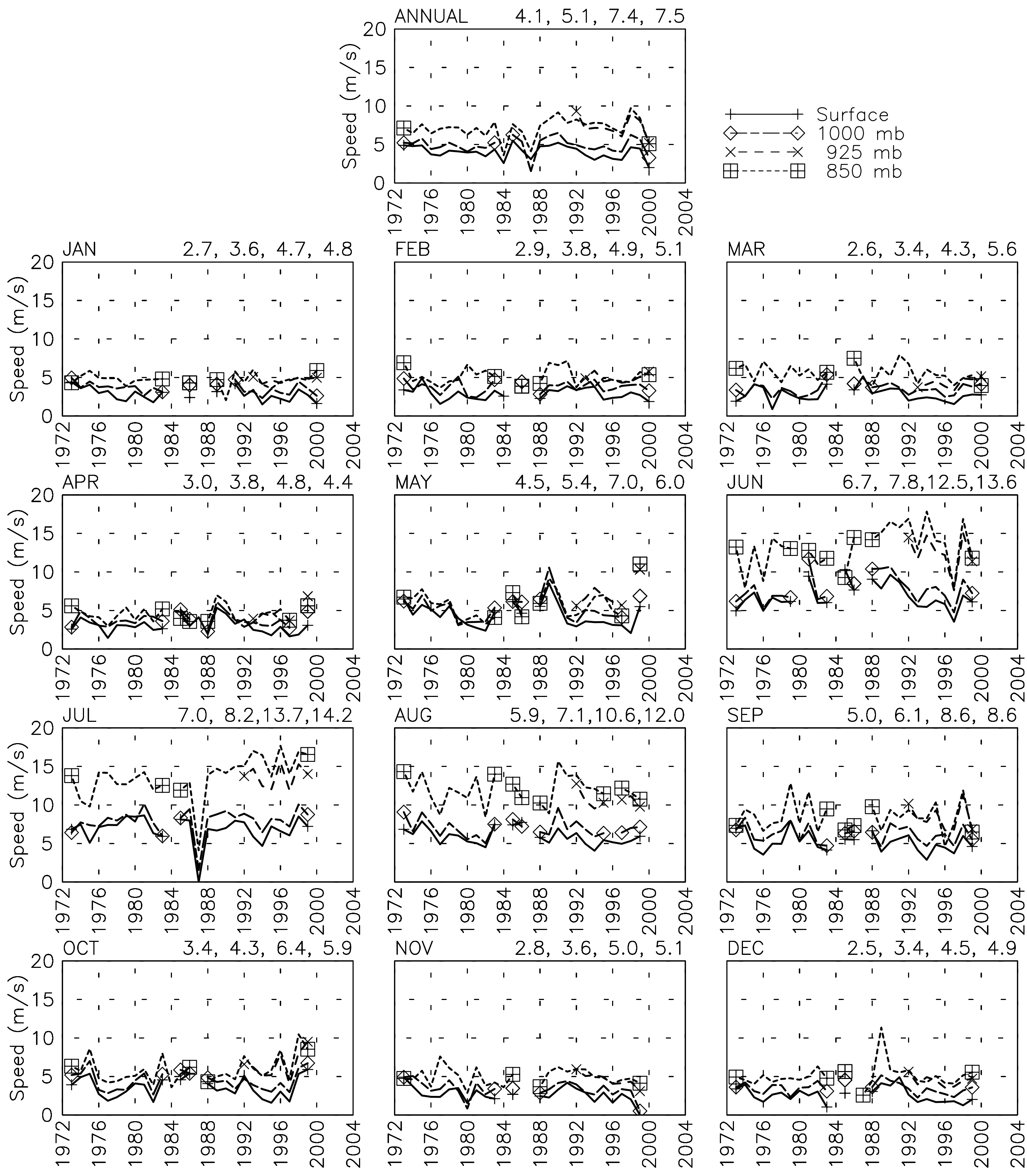
Gan Island – 41350 – 1700 LST
0d 41' S 73d 09' E – Elev 2m
01/73–01/78



Thu Jun 26 12:32:41 2003

SPEED BY PRESSURE LEVEL & YEAR

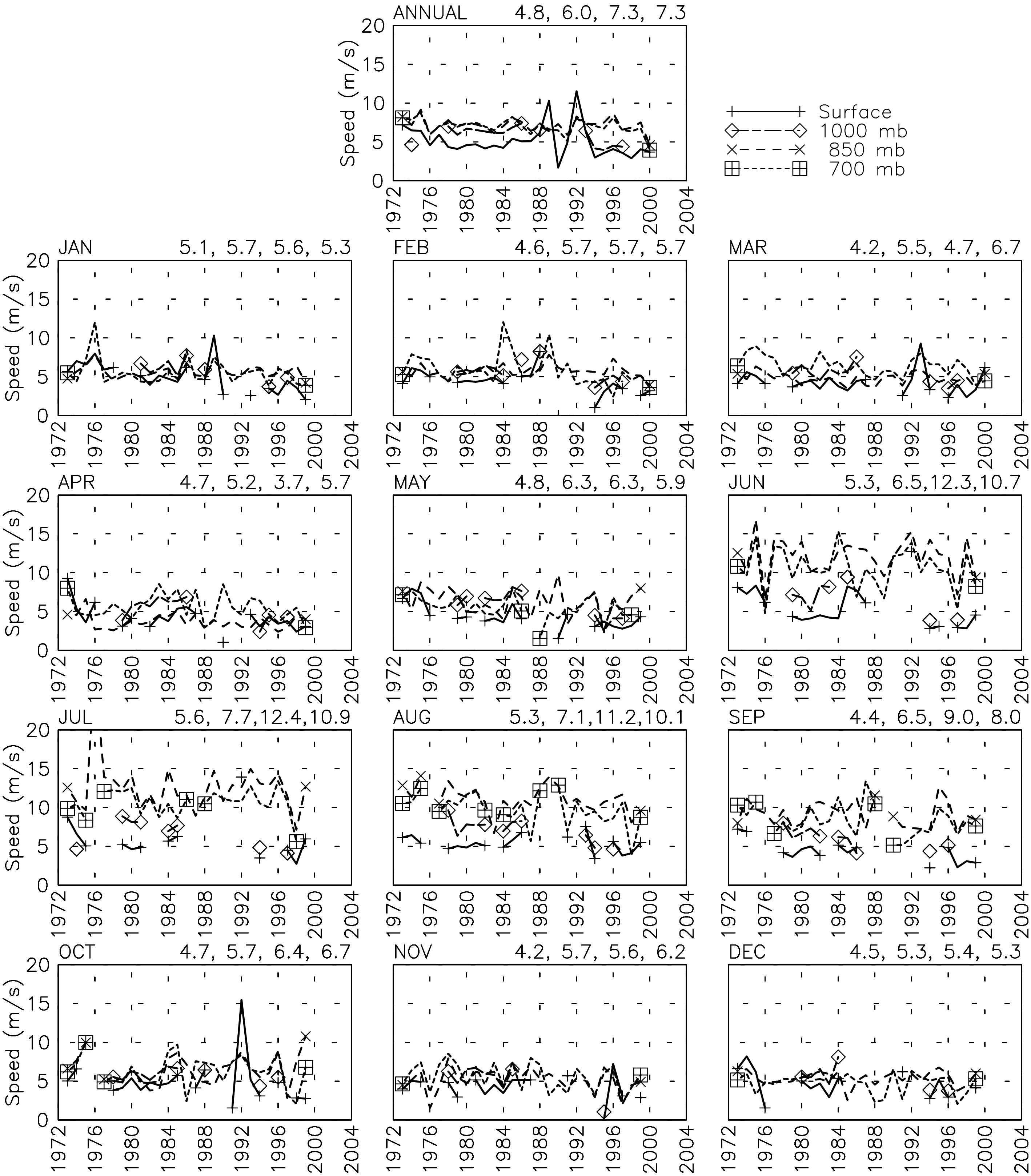
Minicoy Island – 43369 – 1700 LST
8d 18' N 73d 09' E – Elev 1m
01/73–03/00



Thu Jun 26 12:22:18 2003

SPEED BY PRESSURE LEVEL & YEAR

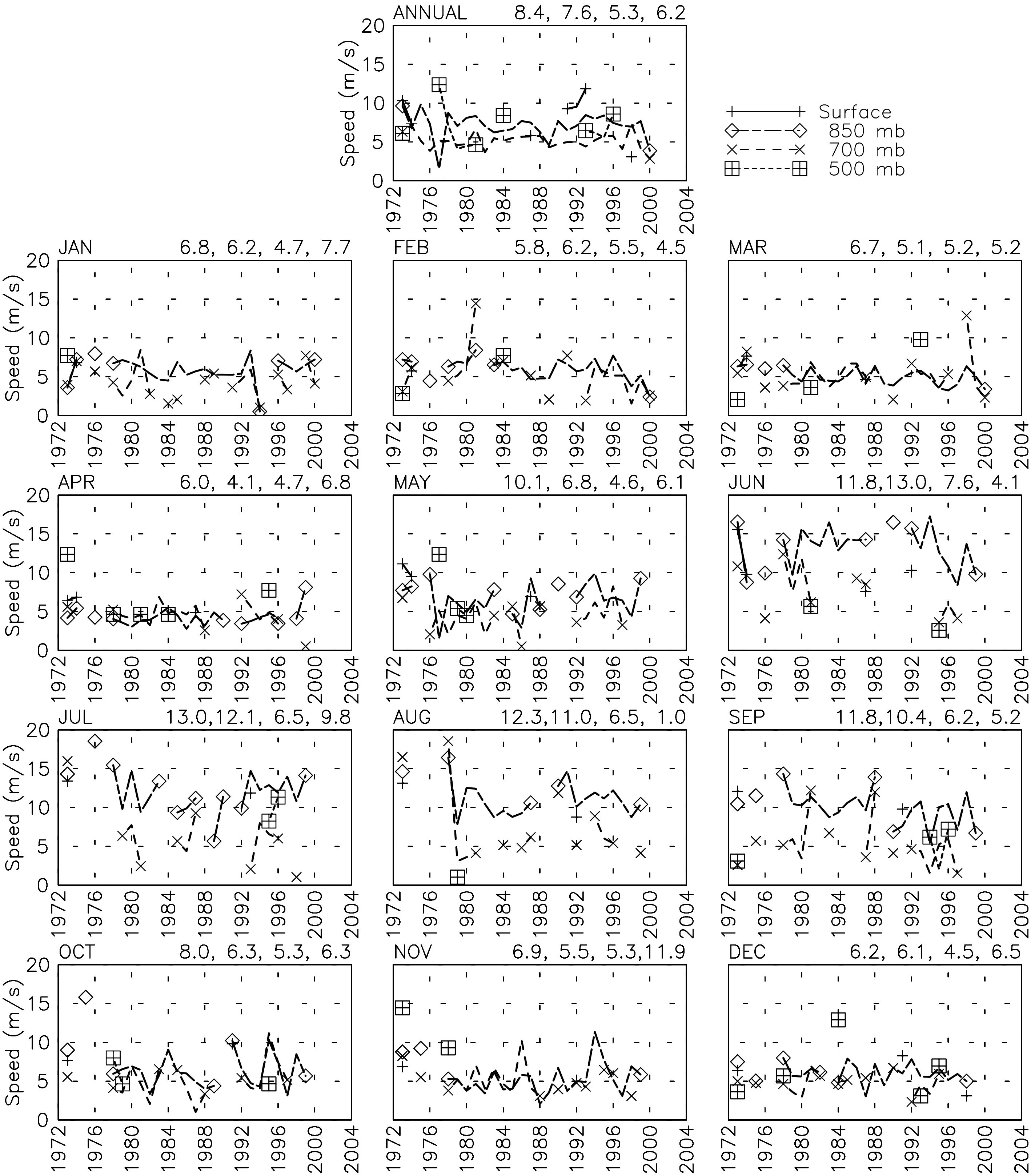
Colombo – 43466 – 1700 LST
6d 54' N 79d 52' E – Elev 7m
01/73–03/00



Thu Jun 26 12:23:07 2003

SPEED BY PRESSURE LEVEL & YEAR

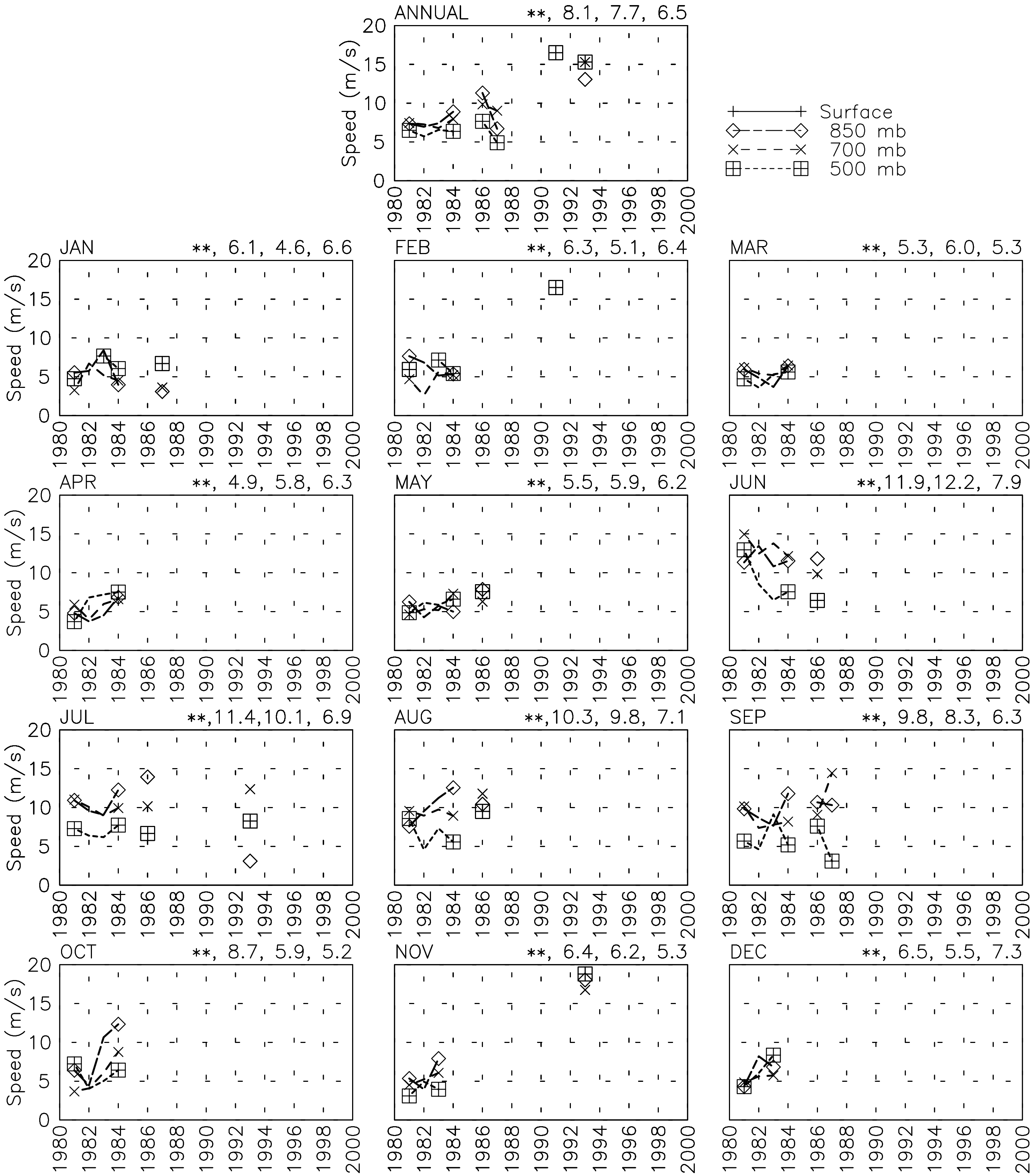
Hambantota – 43497 – 1700 LST
6d 07' N 81d 08' E – Elev 18m
01/73–03/00



Thu Jun 26 12:25:08 2003

SPEED BY PRESSURE LEVEL & YEAR

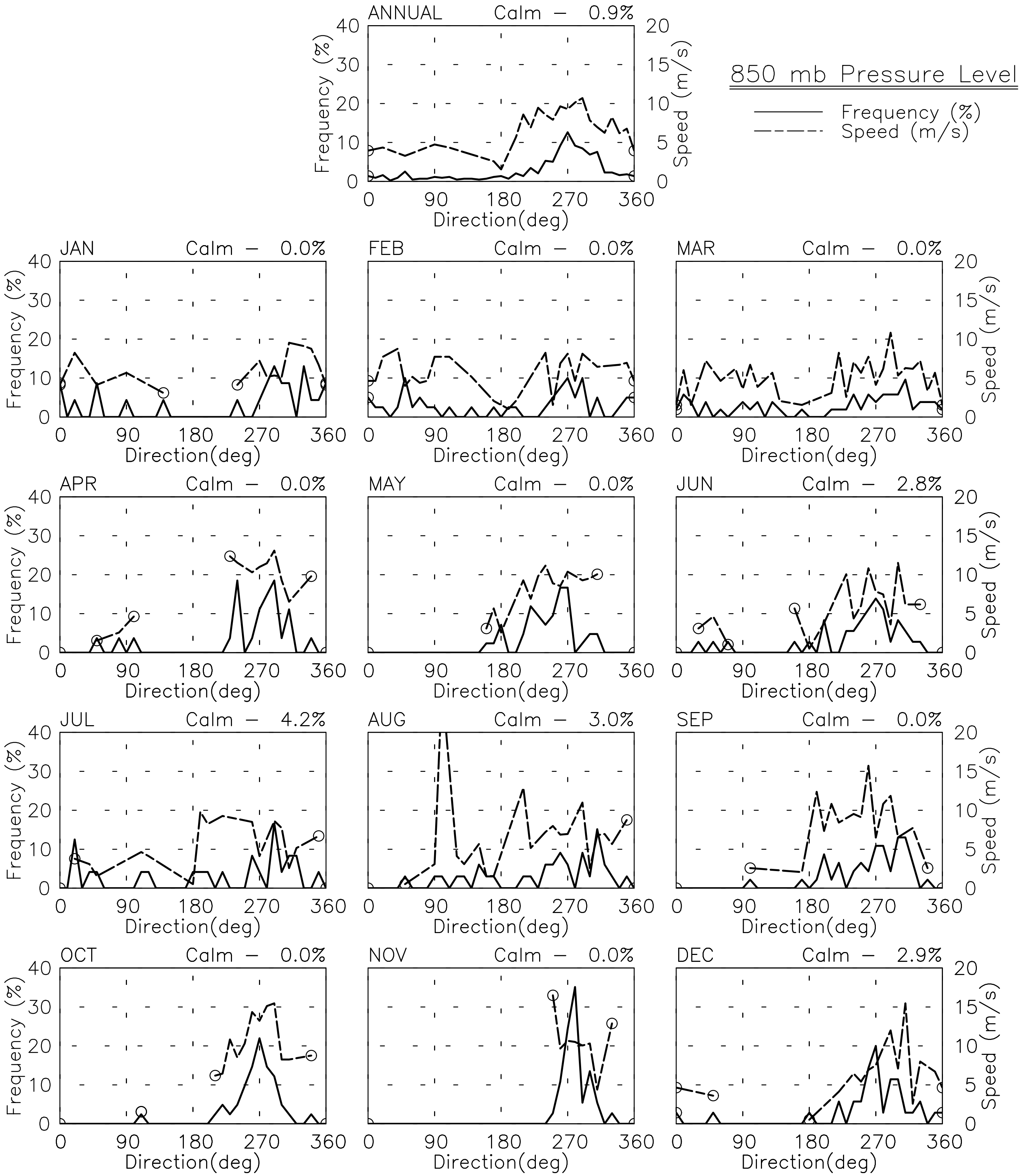
Male – 43555 – 1700 LST
4d 12' N 73d 12' E – Elev 6m
01/81–07/99



Thu Jun 26 12:25:22 2003

FREQUENCY & SPEED BY DIRECTION

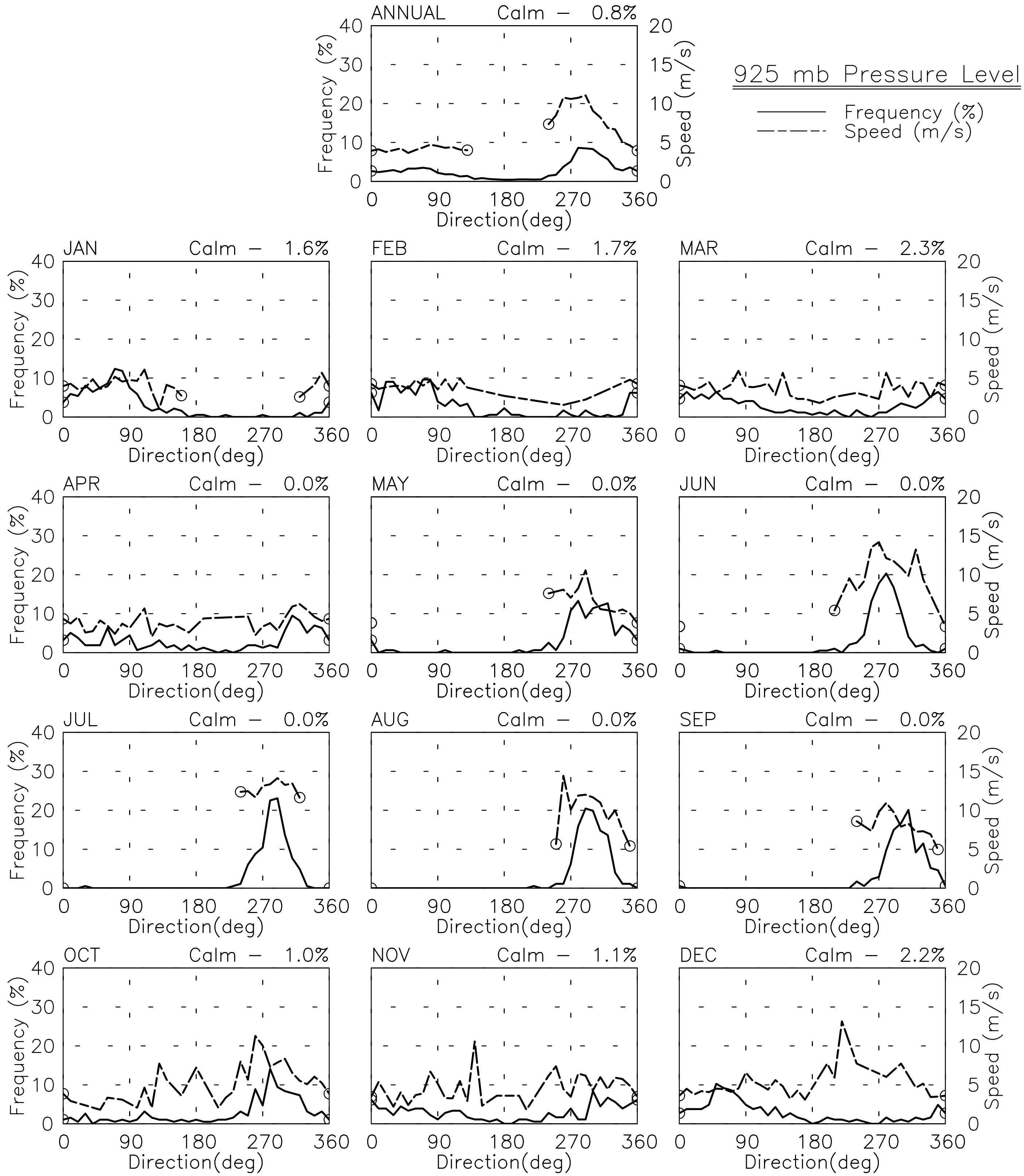
Gan Island – 41350 – 0500 LST
0° 41' S   73° 09' E – Elev   2m
01/73–01/78



Thu Jun 26 12:32:44 2003

FREQUENCY & SPEED BY DIRECTION

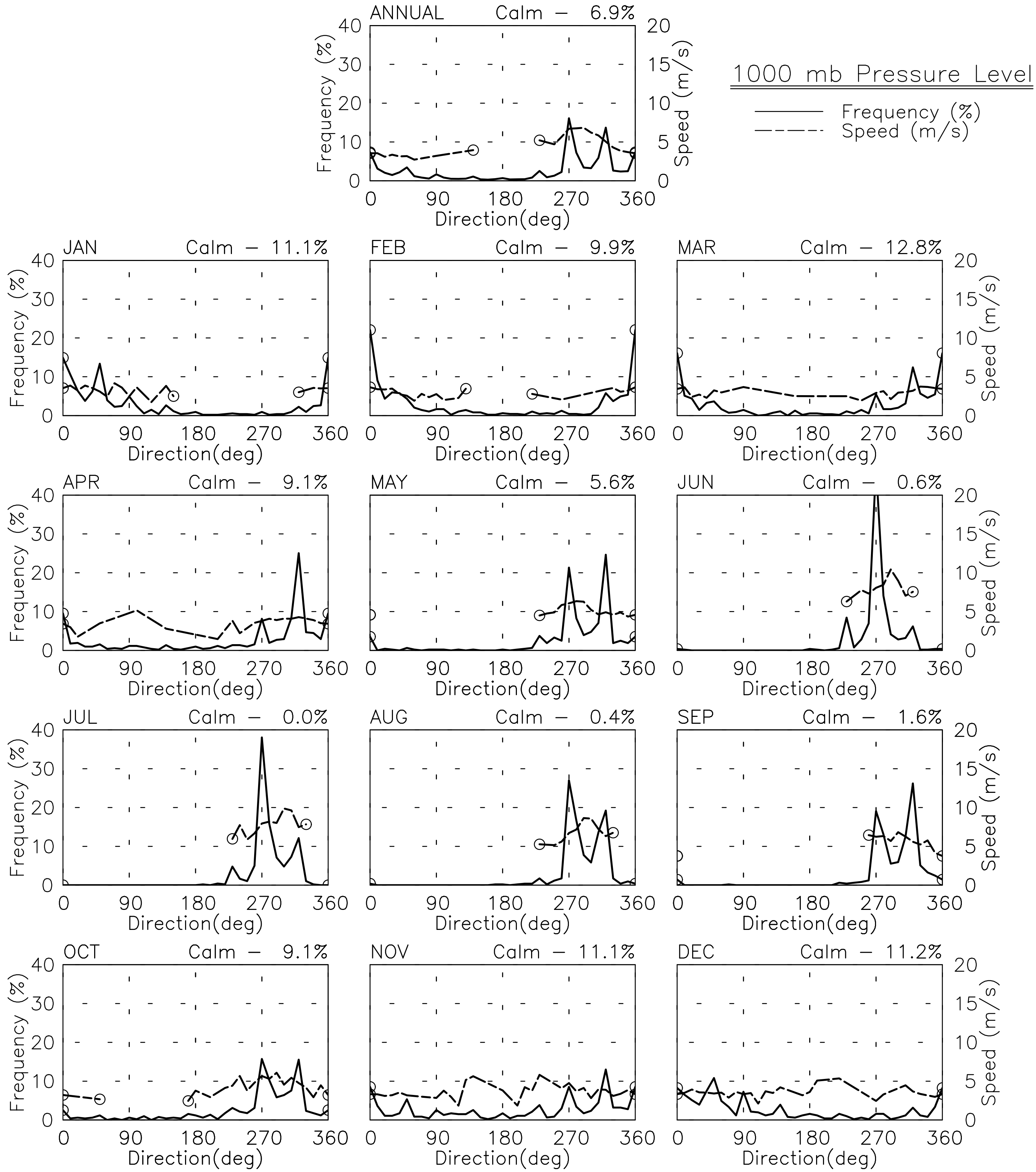
Minicoy Island – 43369 – 0500 LST
8° 18' N 73° 09' E – Elev 1m
01/73–03/00



Thu Jun 26 12:22:26 2003

FREQUENCY & SPEED BY DIRECTION

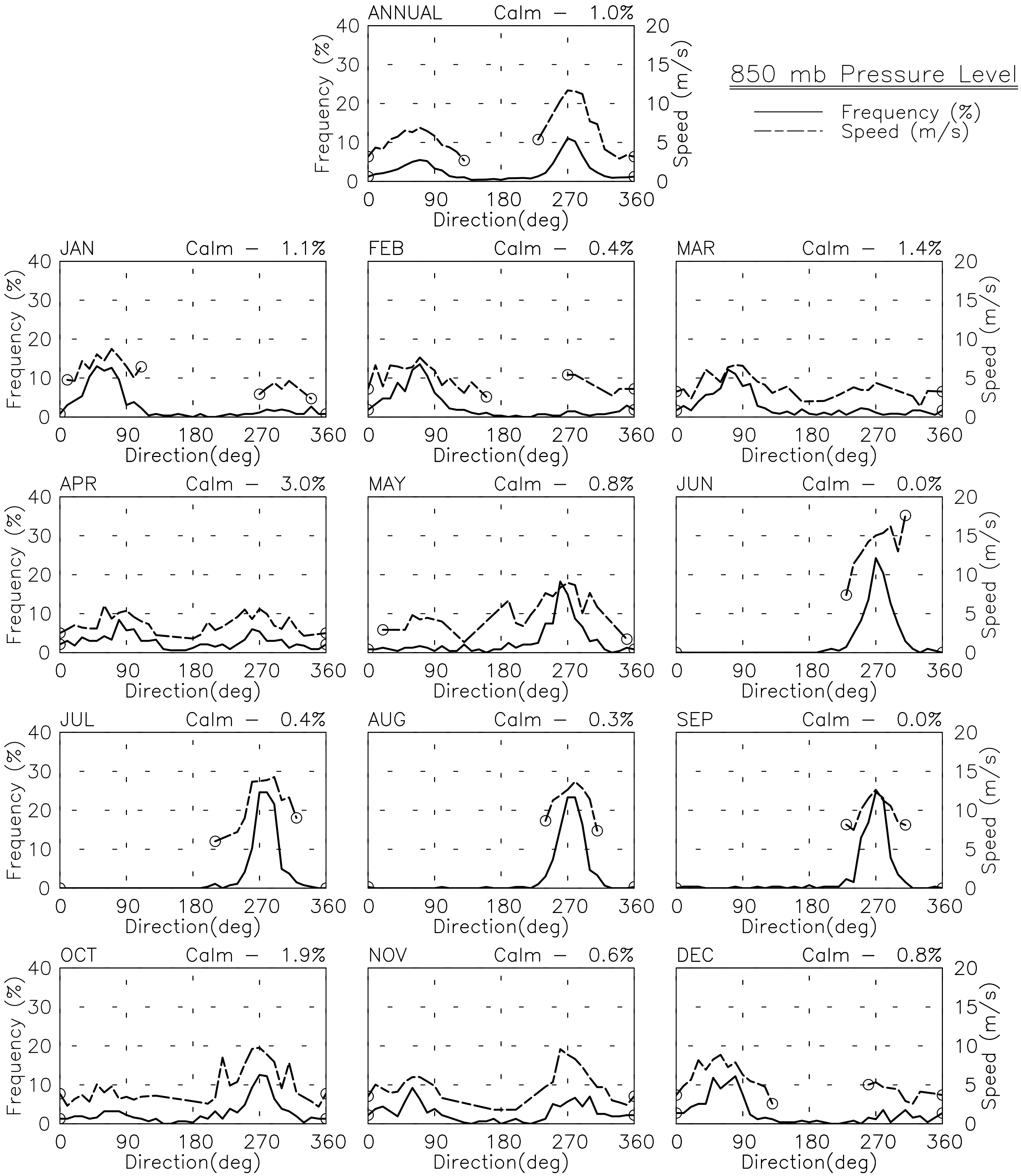
Minicoy Island – 43369 – 0500 LST
8° 18' N 73° 09' E – Elev 1m
01/73–03/00



Thu Jun 26 12:22:25 2003

FREQUENCY & SPEED BY DIRECTION

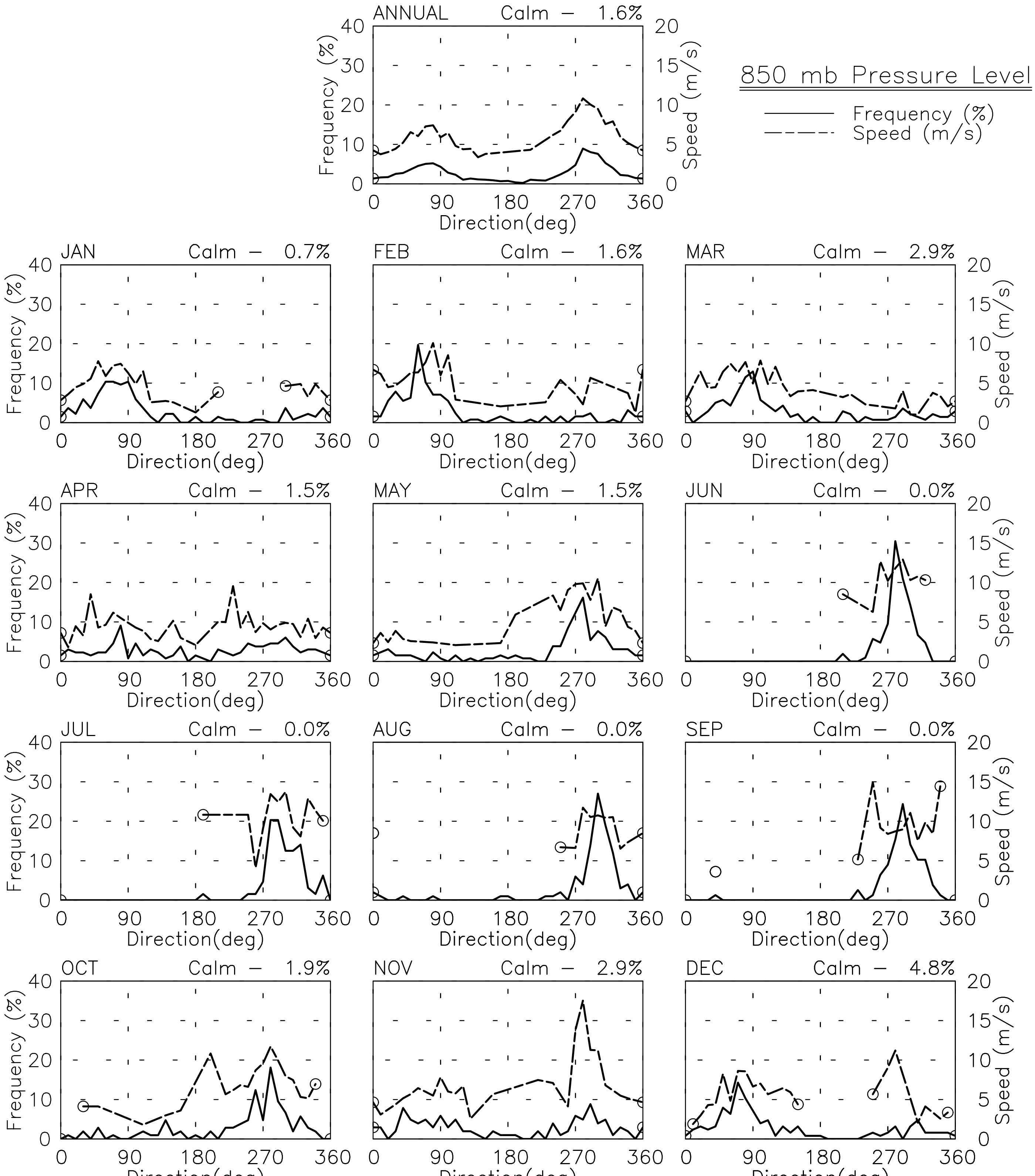
Hambantota – 43497 – 0500 LST
6° 07' N 81° 08' E – Elev 18m
01/73–03/00



Thu Jun 26 12:25:11 2003

FREQUENCY & SPEED BY DIRECTION

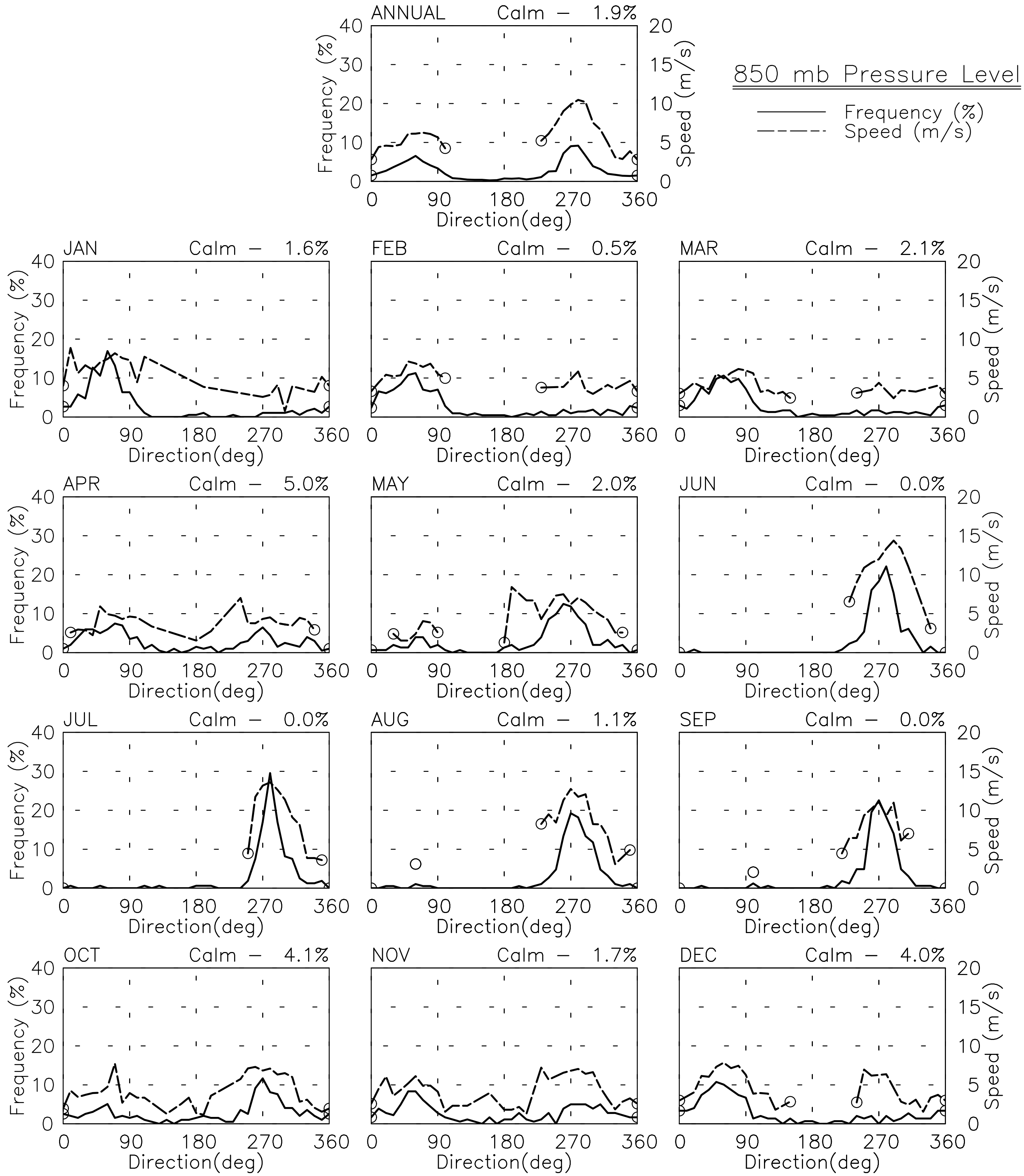
Male – 43555 – 0500 LST
4° 12' N 73° 12' E – Elev 6m
01/81–07/99



Thu Jun 26 12:25:23 2003

FREQUENCY & SPEED BY DIRECTION

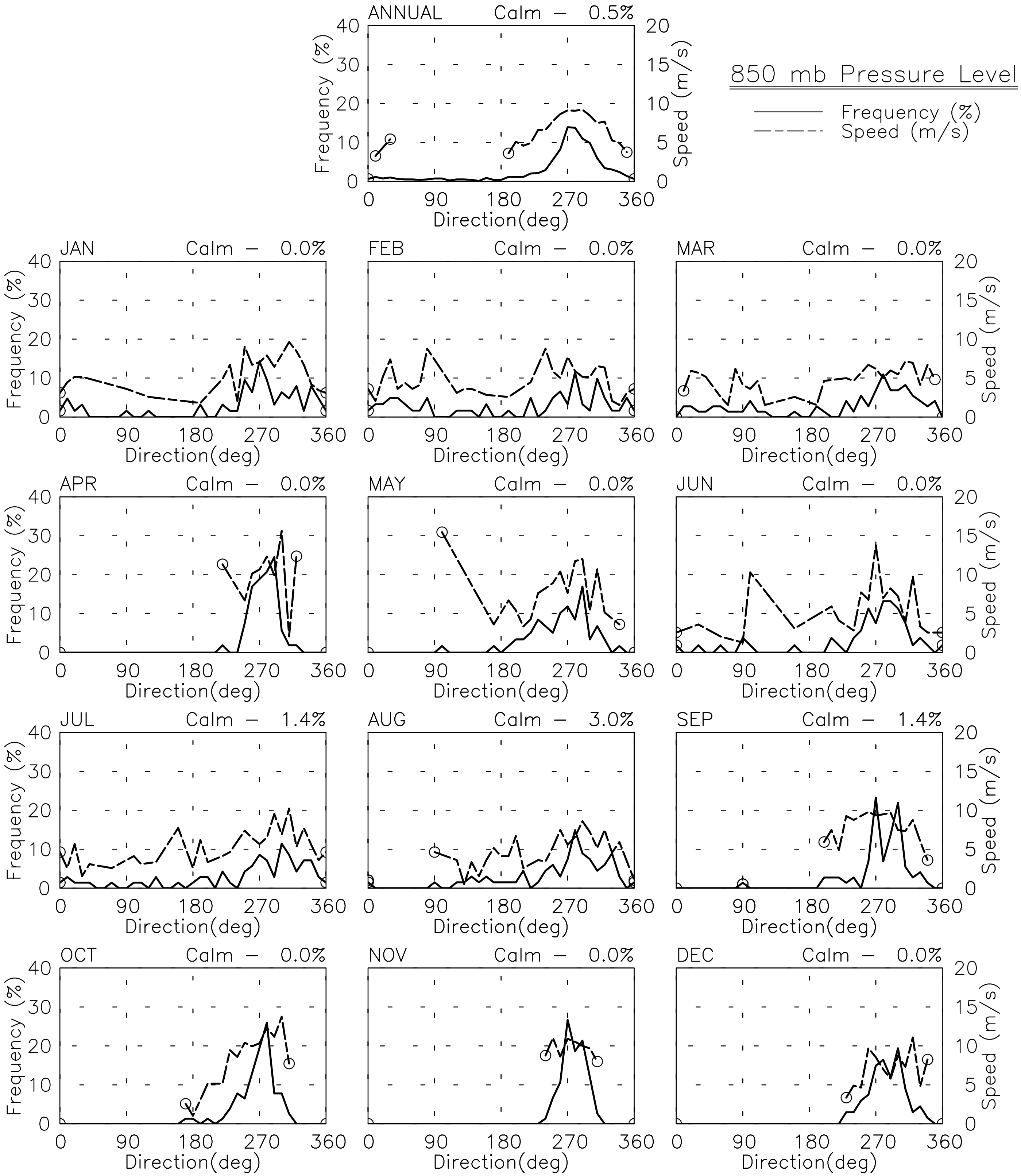
Hambantota – 43497 – 1100 LST
6d 07' N 81d 08' E – Elev 18m
01/73–03/00



Thu Jun 26 12:25:12 2003

FREQUENCY & SPEED BY DIRECTION

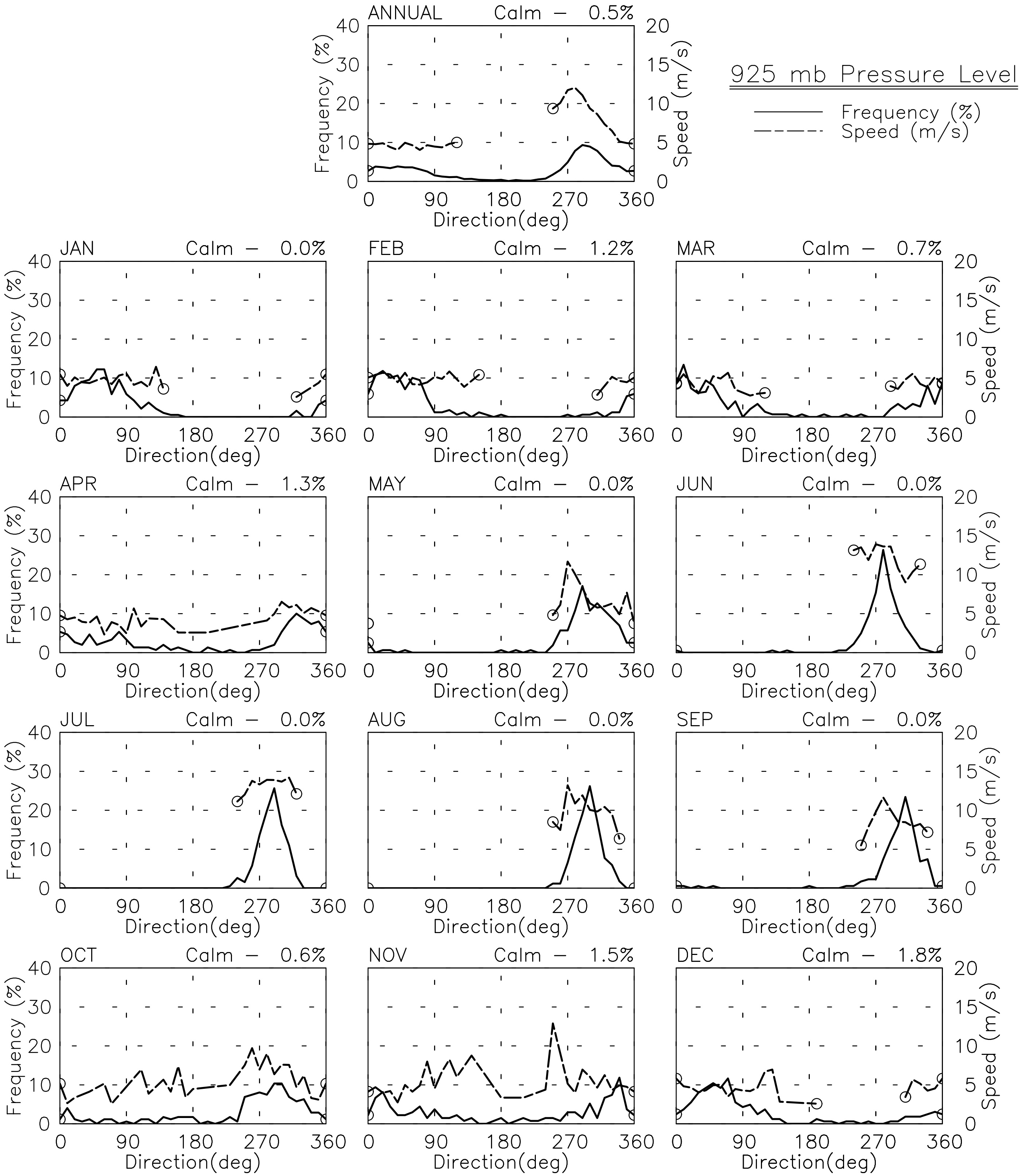
Gan Island – 41350 – 1700 LST
0d 41' S 73d 09' E – Elev 2m
01/73–01/78



Thu Jun 26 12:32:45 2003

FREQUENCY & SPEED BY DIRECTION

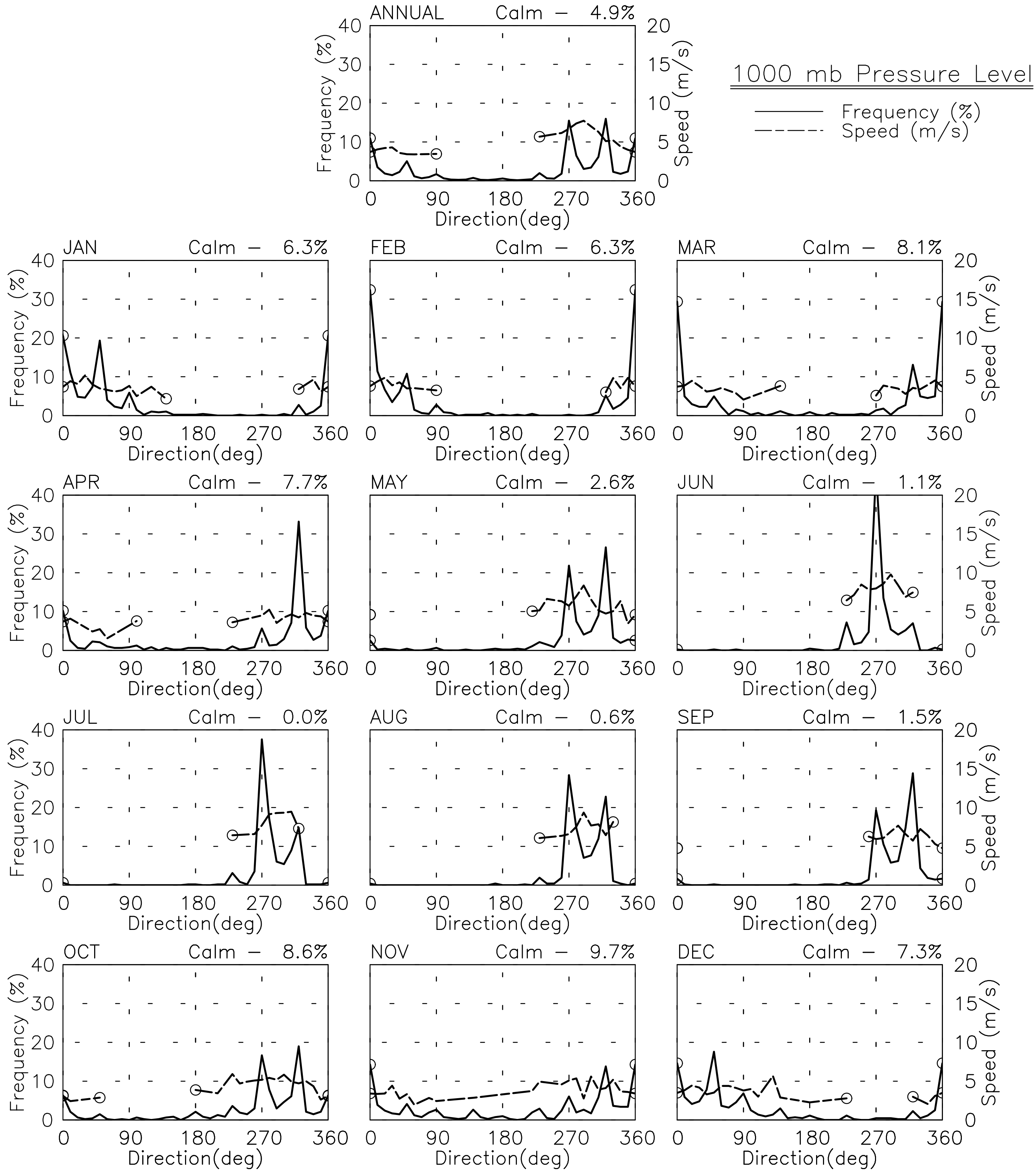
Minicoy Island – 43369 – 1700 LST
8d 18' N 73d 09' E – Elev 1m
01/73–03/00



Thu Jun 26 12:22:27 2003

FREQUENCY & SPEED BY DIRECTION

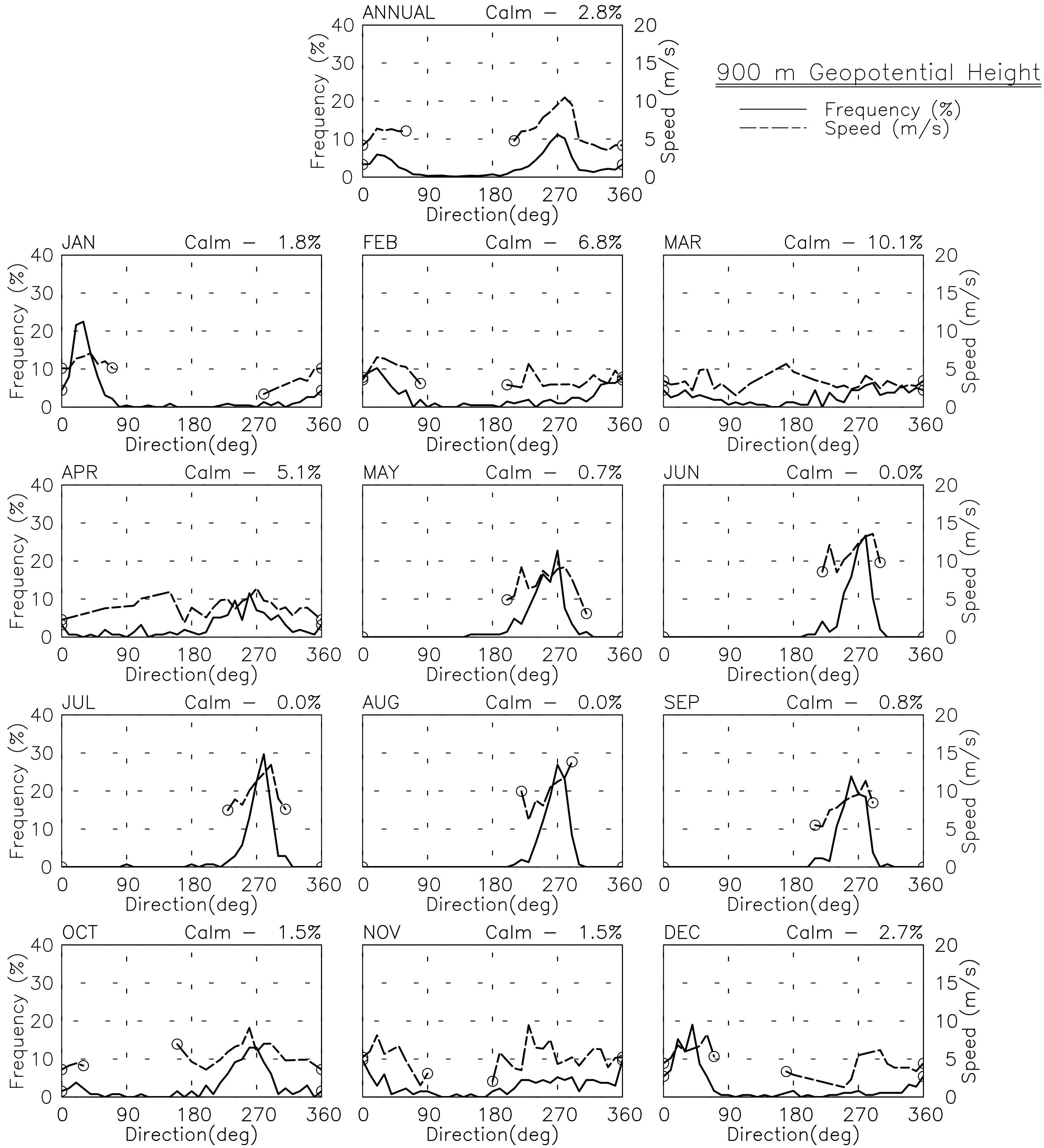
Minicoy Island – 43369 – 1700 LST
8d 18' N 73d 09' E – Elev 1m
01/73–03/00



Thu Jun 26 12:22:25 2003

FREQUENCY & SPEED BY DIRECTION

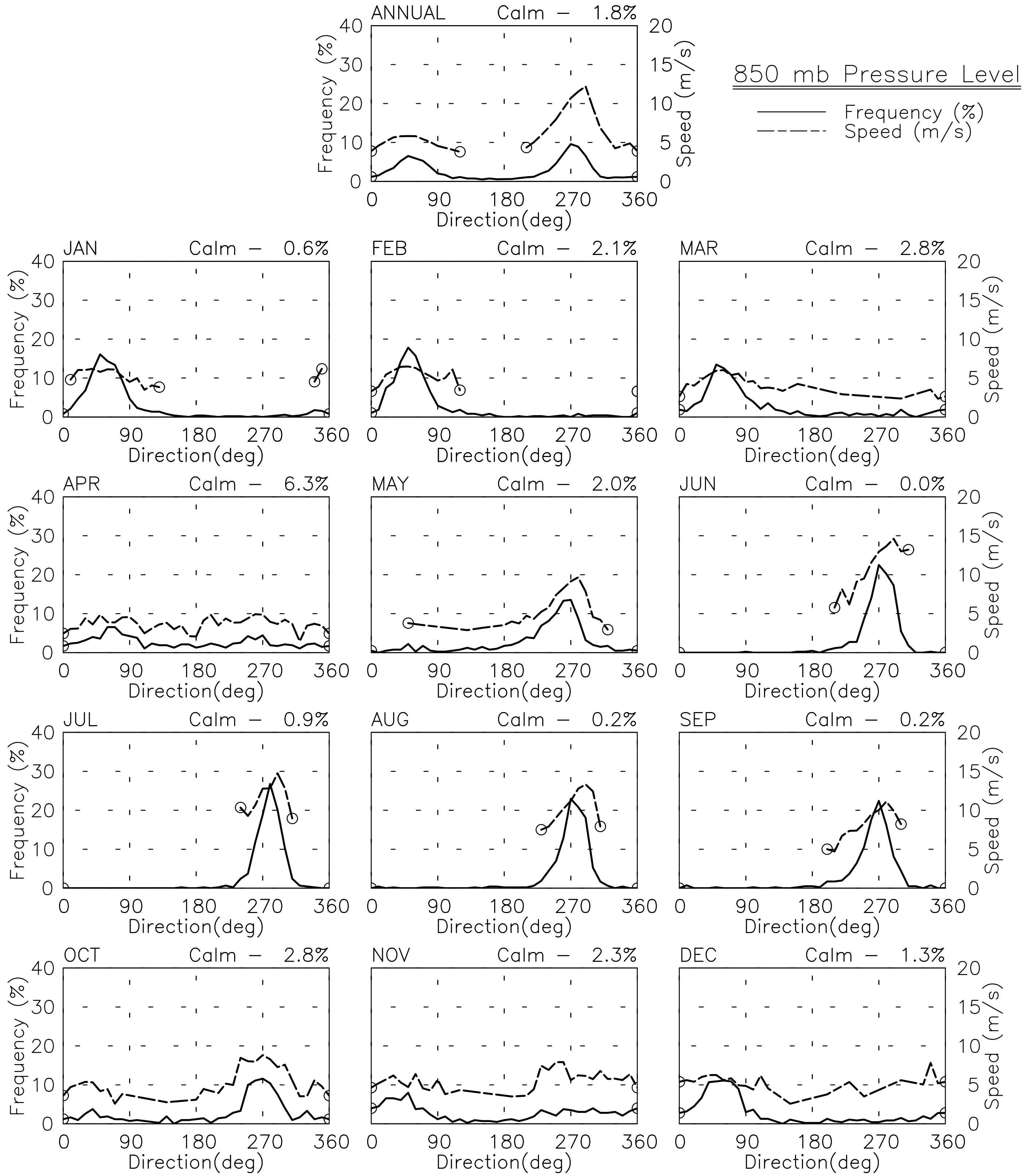
Colombo – 43466 – 1700 LST
6d 54' N 79d 52' E – Elev 7m
01/73–03/00



Thu Jun 26 12:23:16 2003

FREQUENCY & SPEED BY DIRECTION

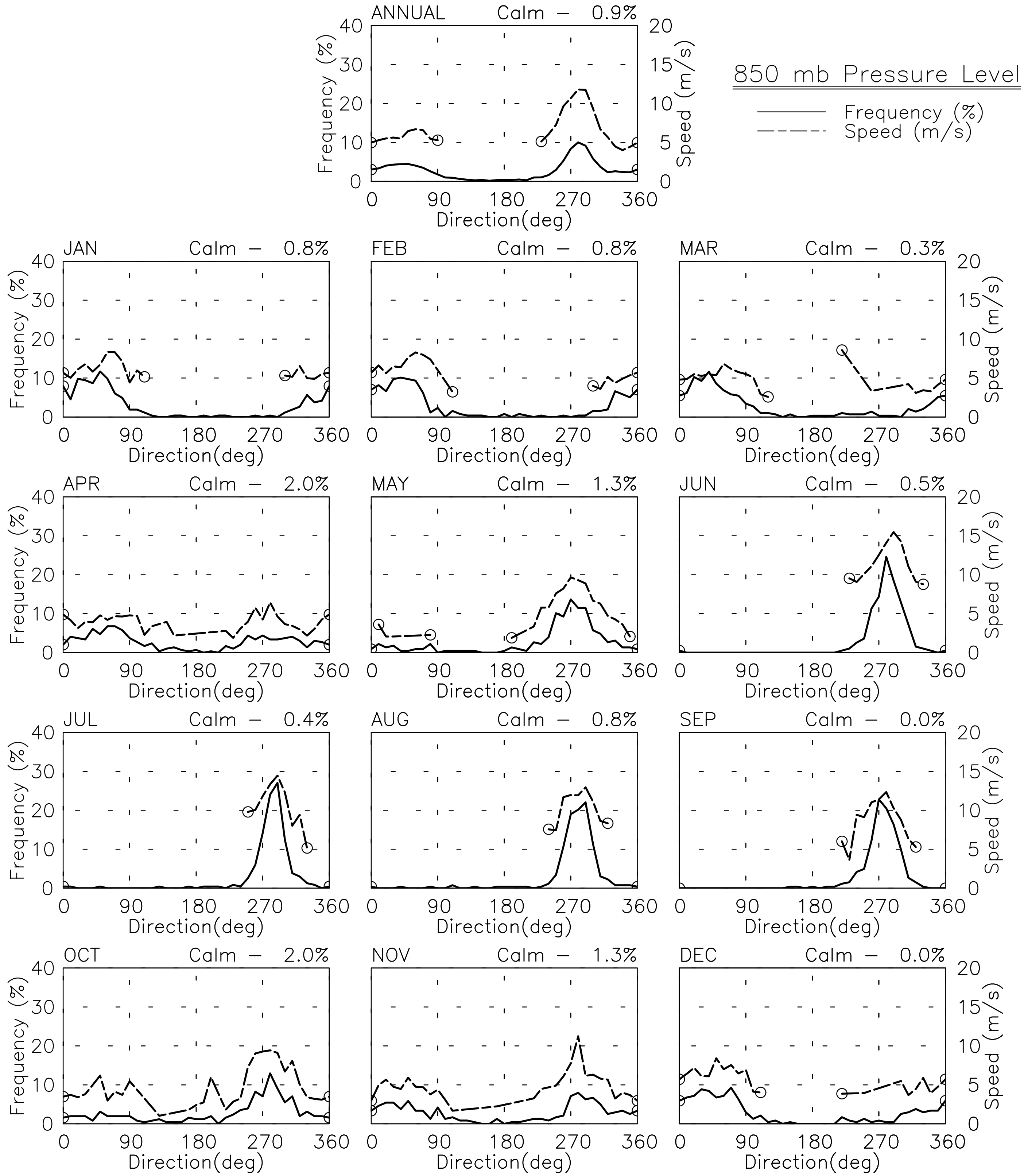
Colombo – 43466 – 1700 LST
6d 54' N 79d 52' E – Elev 7m
01/73–03/00



Thu Jun 26 12:23:15 2003

FREQUENCY & SPEED BY DIRECTION

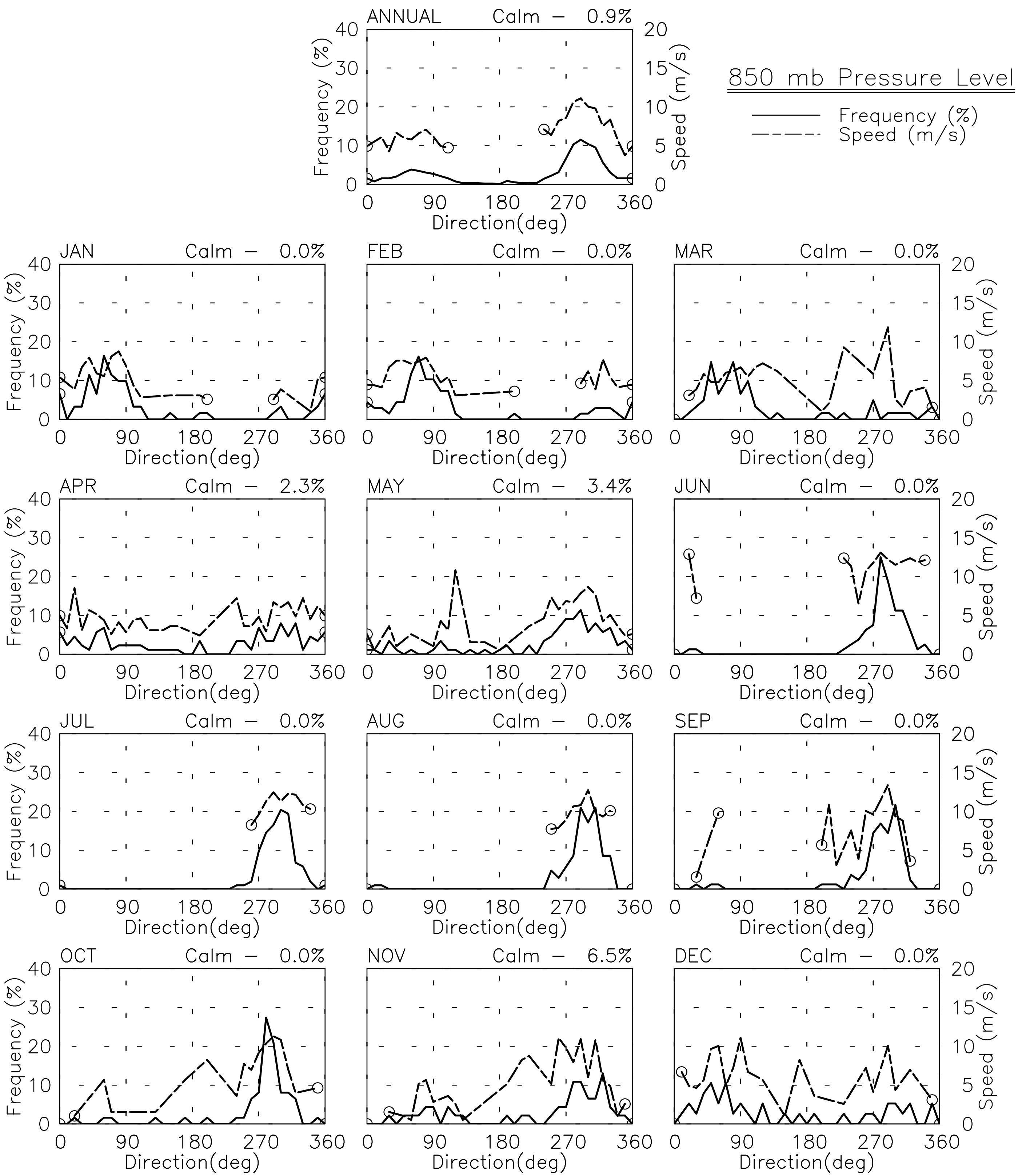
Hambantota – 43497 – 1700 LST
6d 07' N 81d 08' E – Elev 18m
01/73–03/00



Thu Jun 26 12:25:12 2003

FREQUENCY & SPEED BY DIRECTION

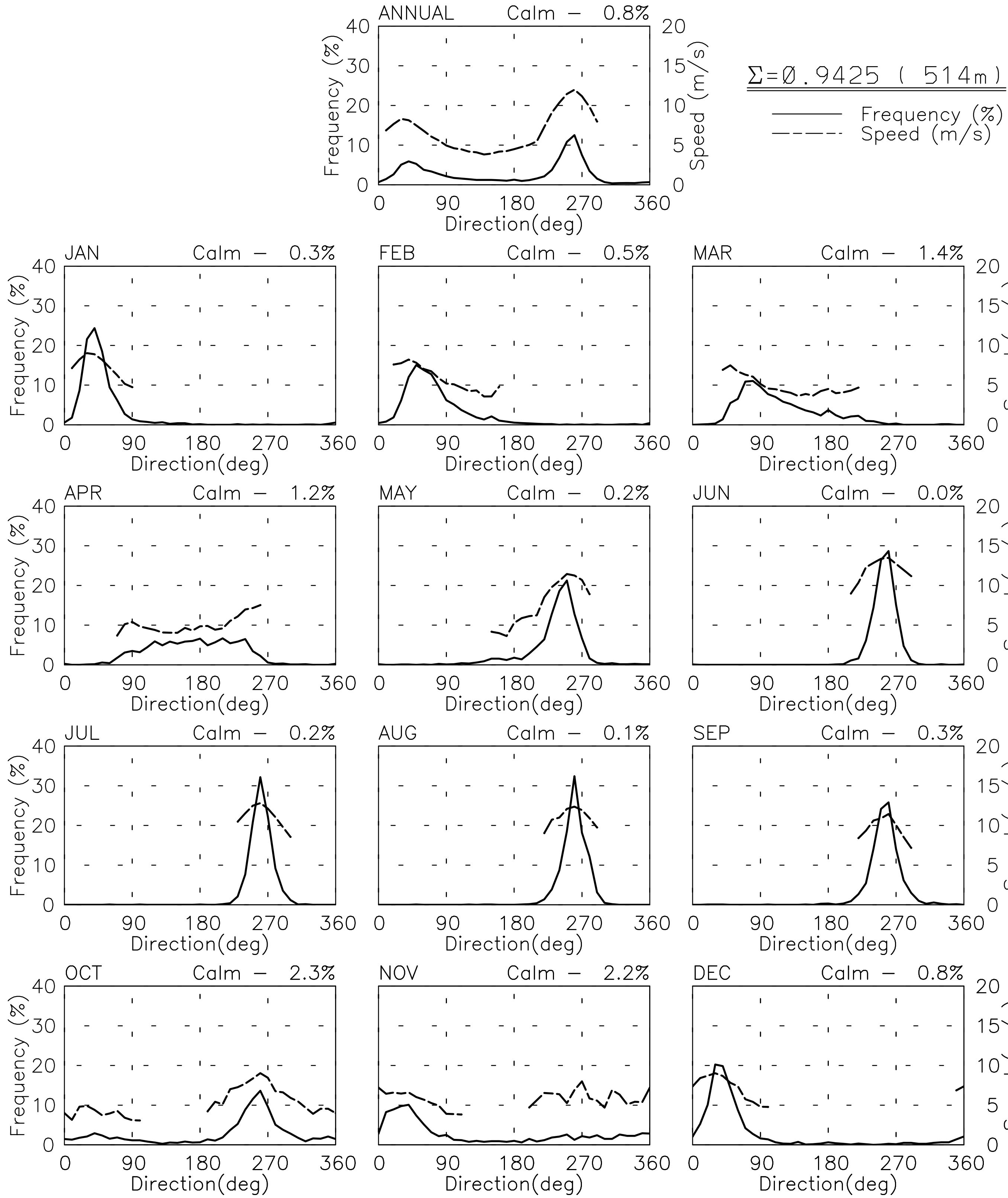
Male – 43555 – 1700 LST
4d 12' N   73d 12' E – Elev   6m
01/81–07/99



Thu Jun 26 12:25:25 2003

FREQUENCY & SPEED BY DIRECTION (SIGMA)

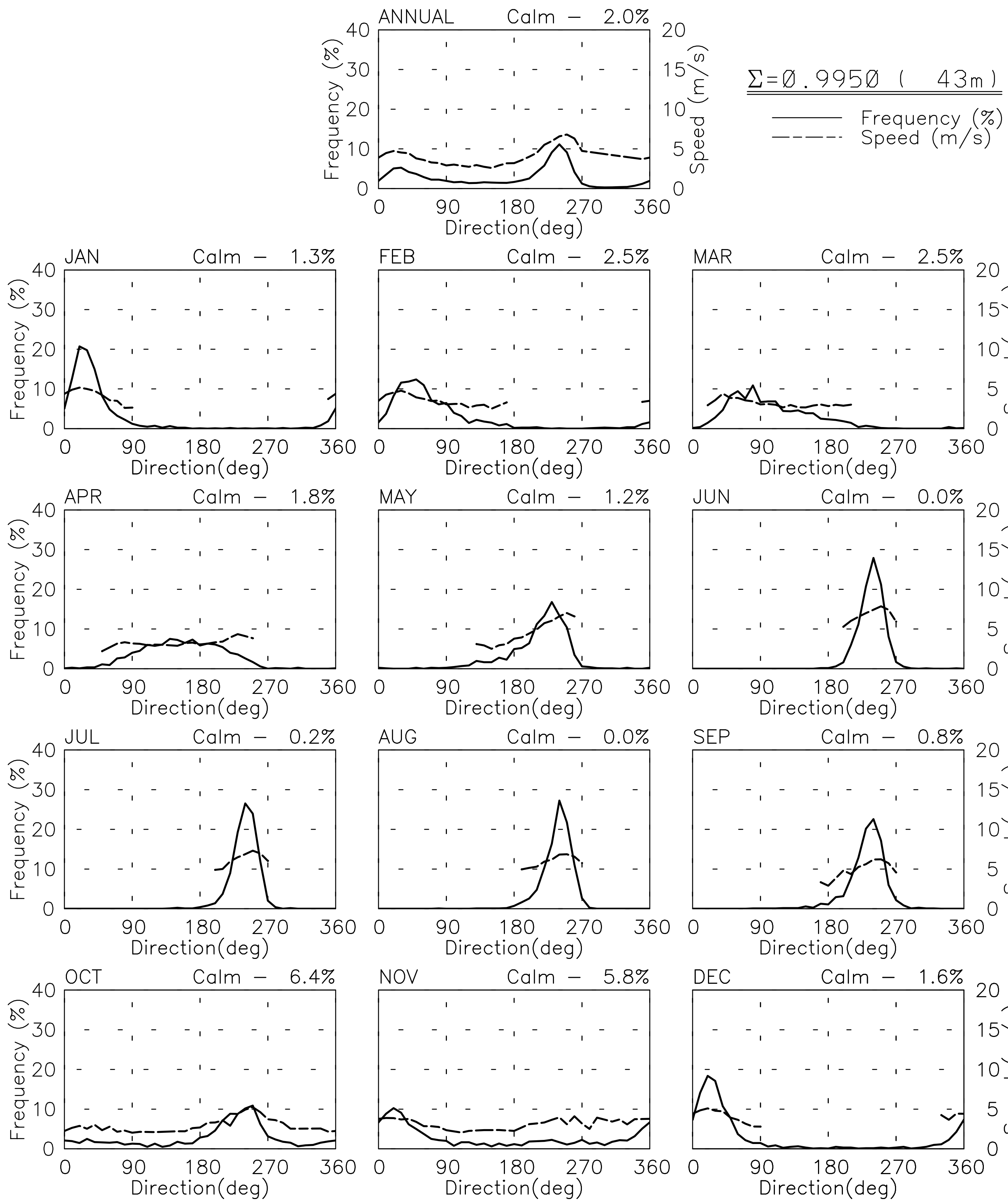
Reanalysis T62 Gauss – 08107 – 0500 LST
8° 34' N 80° 37' E – Elev –18m
01/58–12/97



Tue Jun 24 12:33:33 2003

FREQUENCY & SPEED BY DIRECTION (SIGMA)

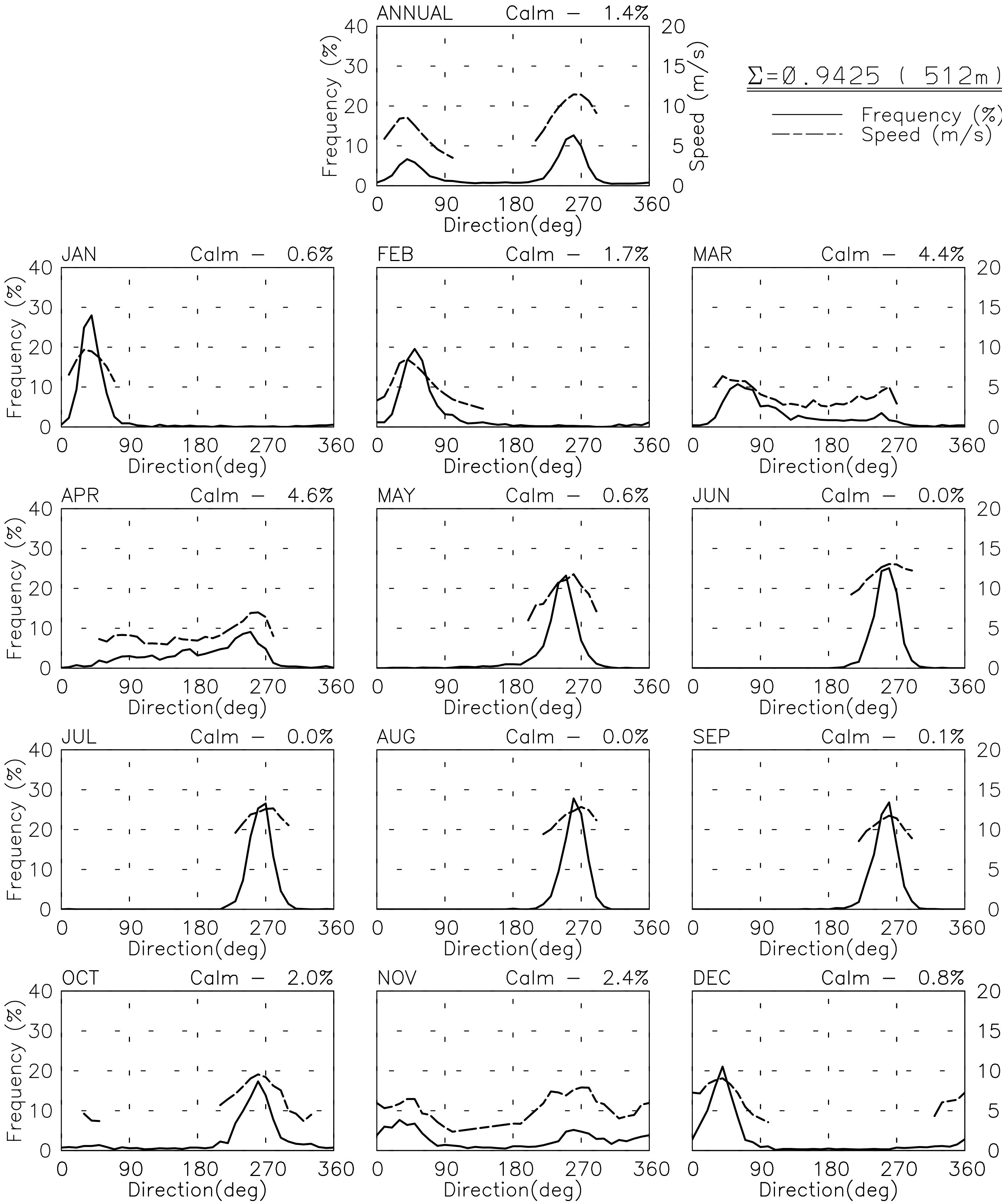
Reanalysis T62 Gauss – 08107 – 0500 LST
8° 34' N   80° 37' E – Elev –18m
01/58–12/97



Tue Jun 24 12:33:32 2003

FREQUENCY & SPEED BY DIRECTION (SIGMA)

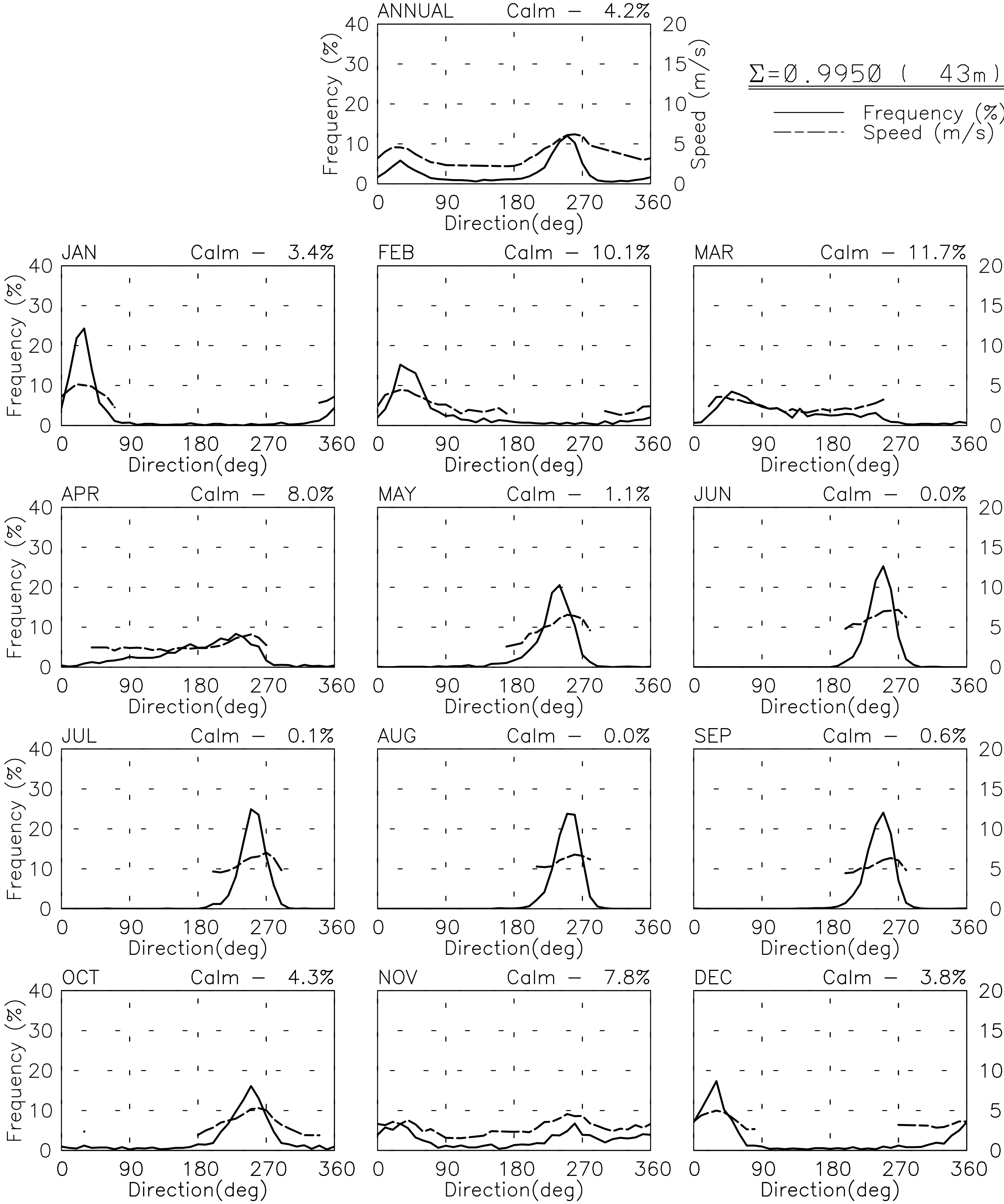
Reanalysis T62 Gauss – 08299 – 0500 LST
6° 40' N 80° 37' E – Elev 115m
01/58–12/97



Tue Jun 24 12:33:57 2003

FREQUENCY & SPEED BY DIRECTION (SIGMA)

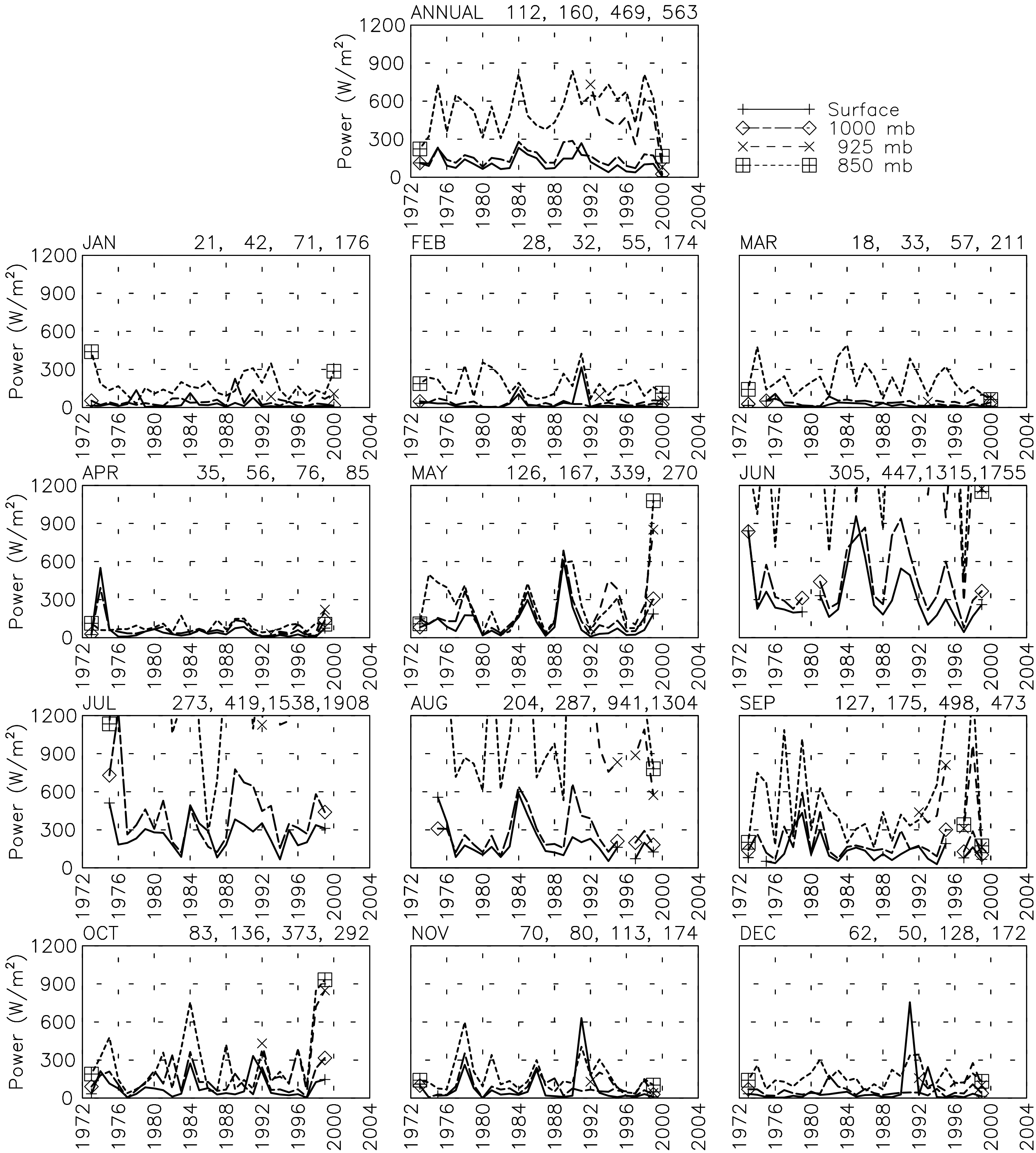
Reanalysis T62 Gauss – 08299 – 0500 LST
6° 40' N 80° 37' E – Elev 115m
01/58–12/97



Tue Jun 24 12:33:56 2003

POWER BY PRESSURE LEVEL & YEAR

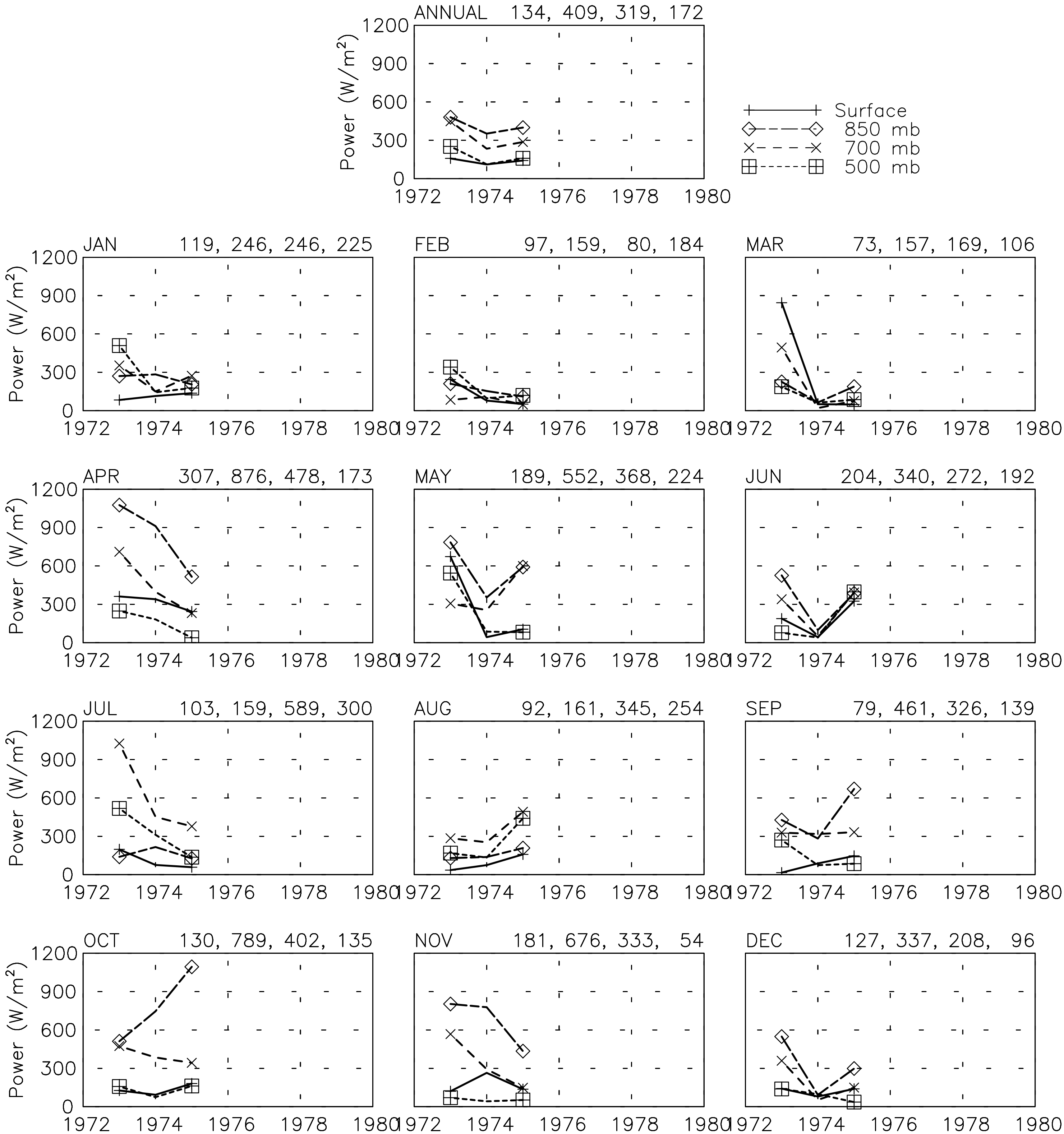
Minicoy Island – 43369 – 0500 LST
8° 18' N 73° 09' E – Elev 1m
01/73–03/00



Thu Jun 26 12:22:21 2003

POWER BY PRESSURE LEVEL & YEAR

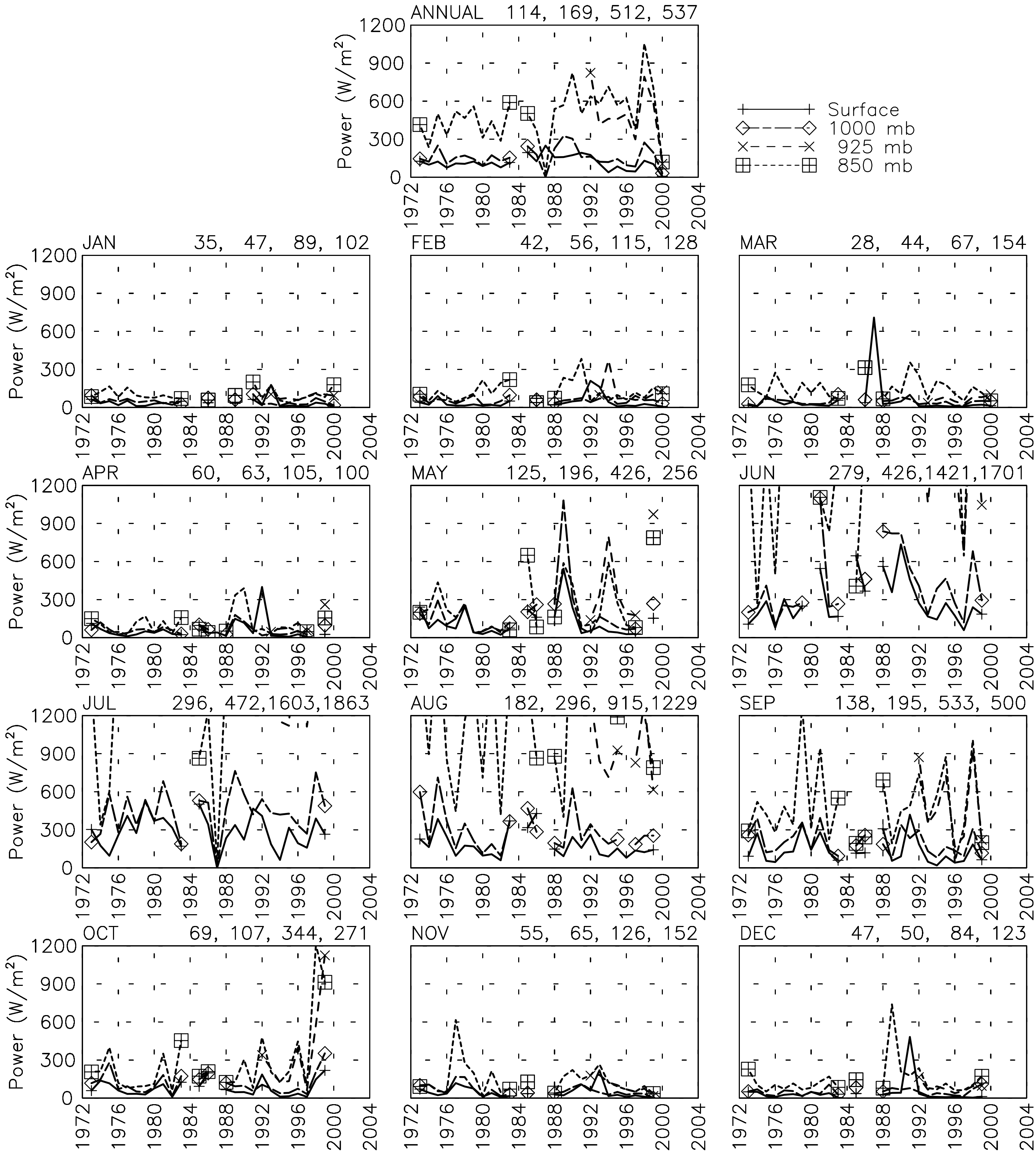
Gan Island – 41350 – 1700 LST
0° 41' S 73° 09' E – Elev 2m
01/73–01/78



Thu Jun 26 12:32:43 2003

POWER BY PRESSURE LEVEL & YEAR

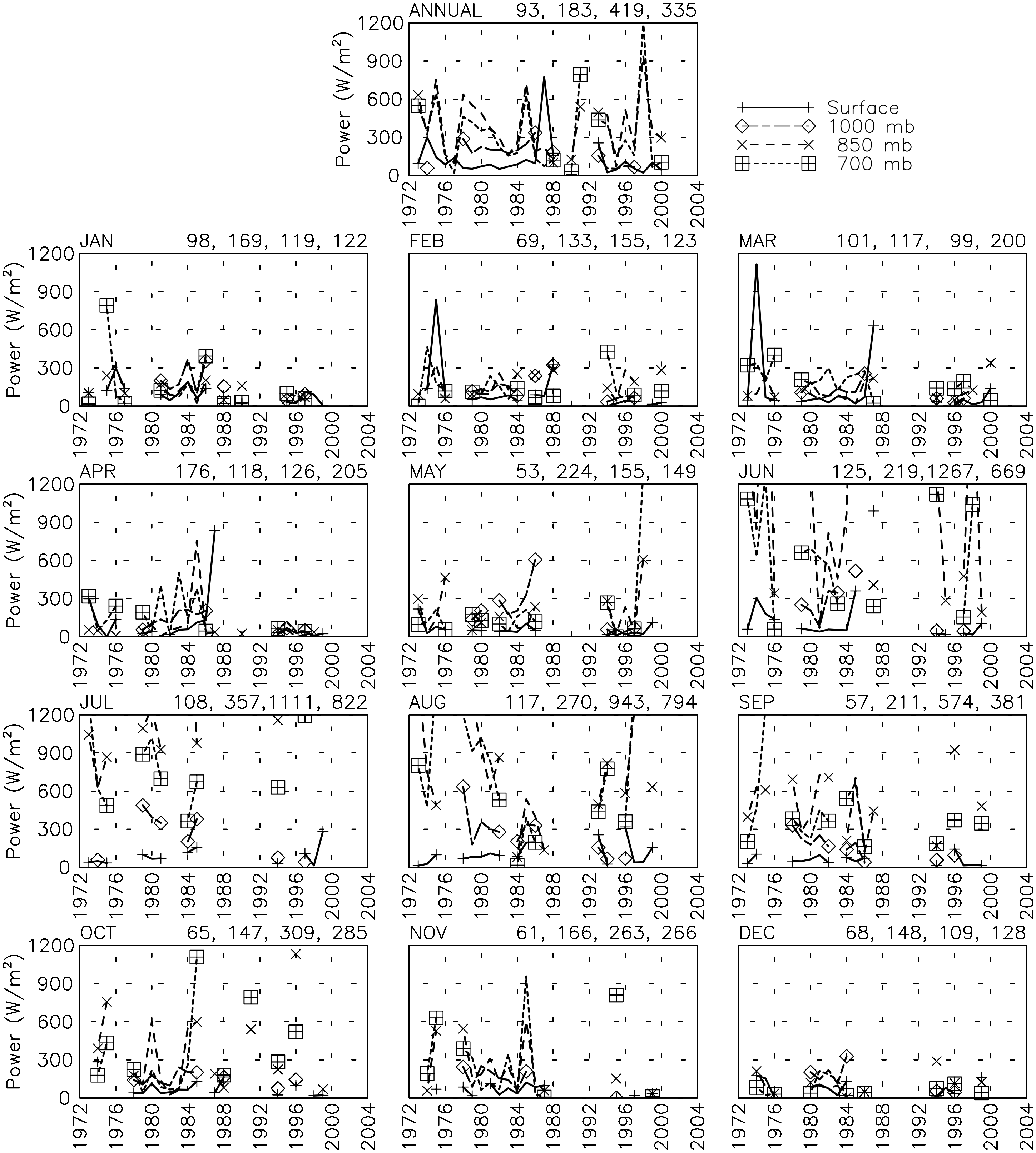
Minicoy Island – 43369 – 1700 LST
8d 18' N 73d 09' E – Elev 1m
01/73–03/00



Thu Jun 26 12:22:22 2003

POWER BY PRESSURE LEVEL & YEAR

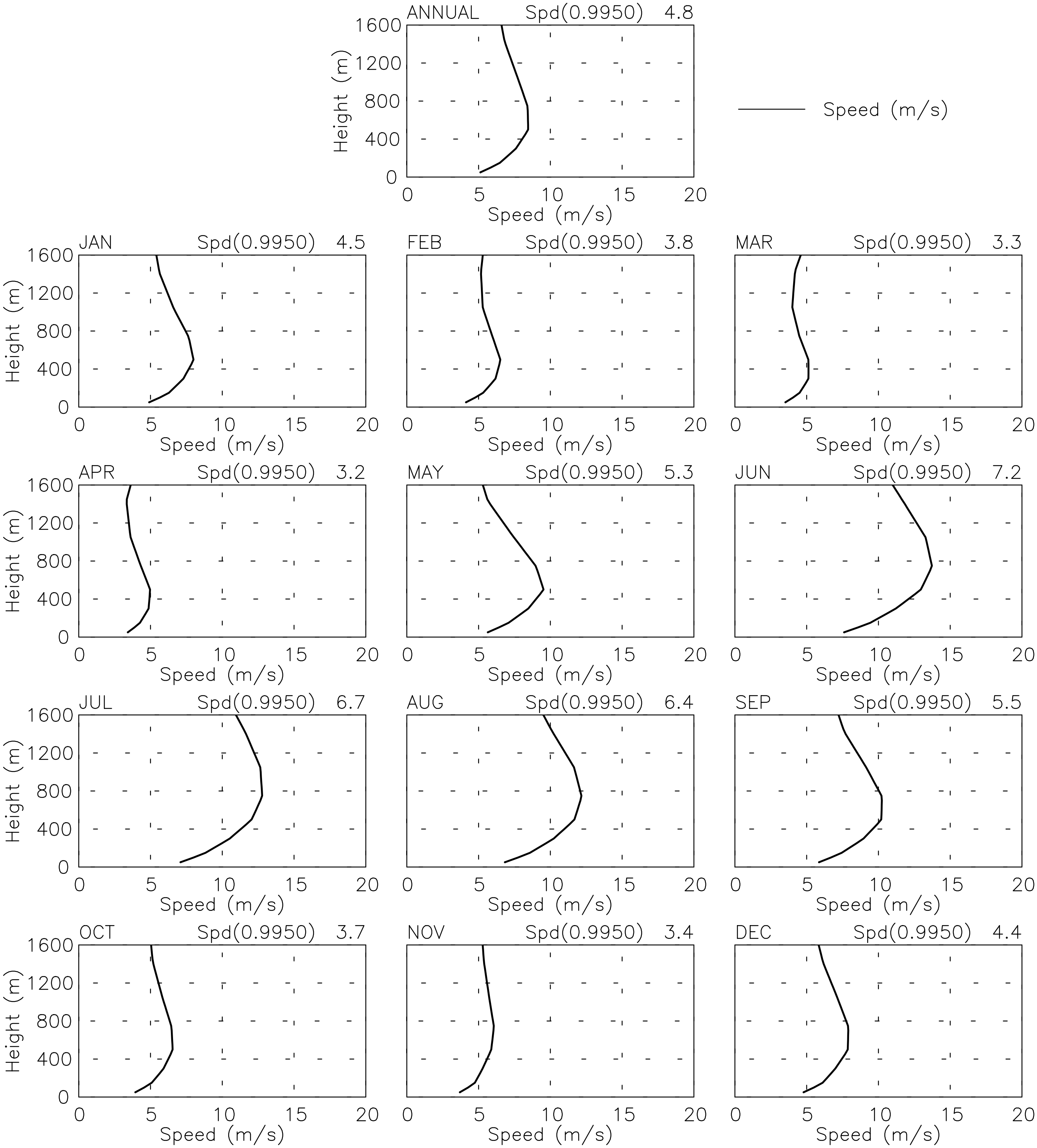
Colombo – 43466 – 1700 LST
6° 54' N 79° 52' E – Elev 7m
01/73–03/00



Thu Jun 26 12:23:09 2003

VERTICAL WIND SPEED PROFILE BY HEIGHT

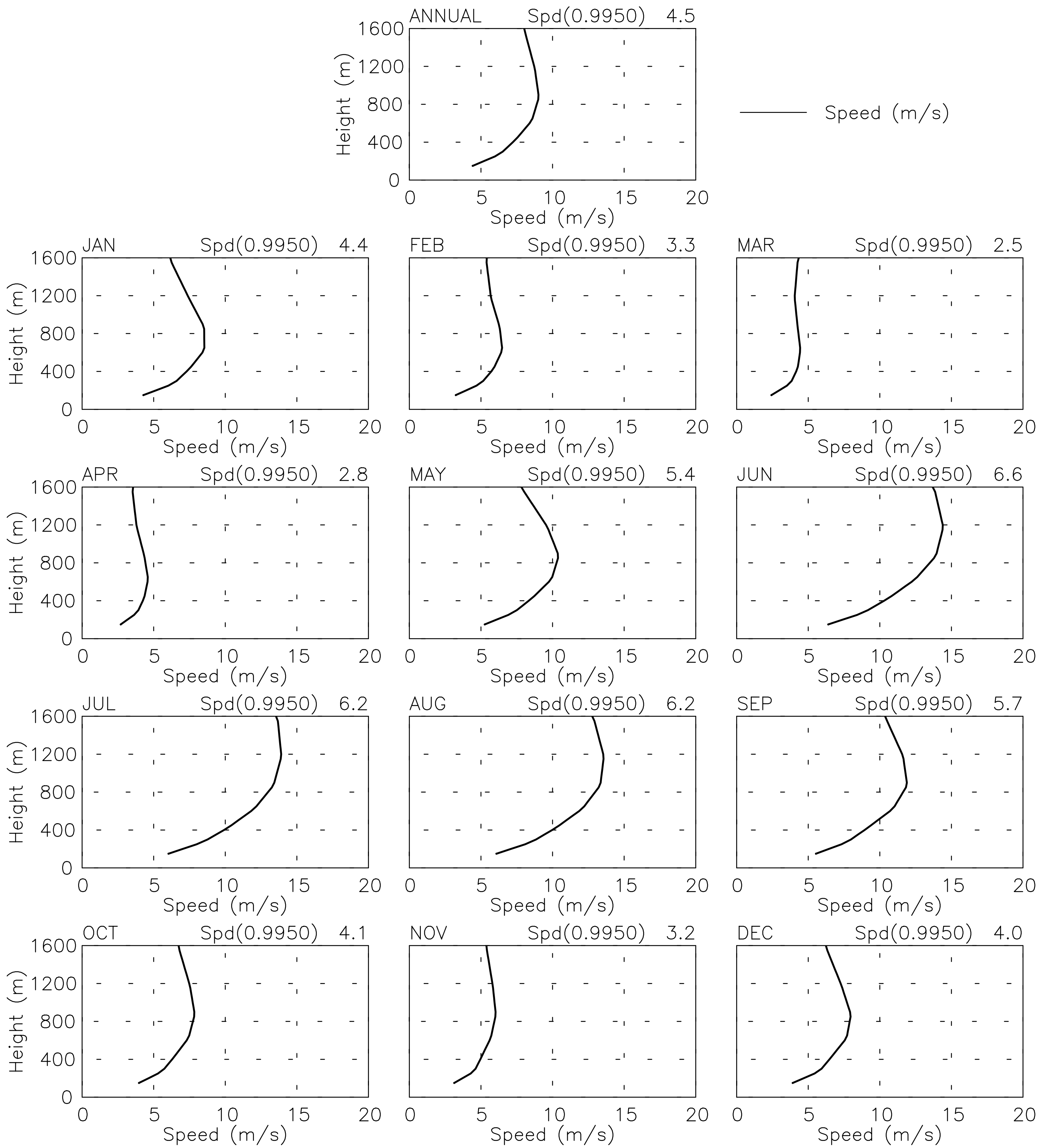
Reanalysis T62 Gauss – 08107 – 0500 LST
8° 34' N   80° 37' E – Elev –18m
01/58–12/97



Tue Jun 24 12:33:31 2003

VERTICAL WIND SPEED PROFILE BY HEIGHT

Reanalysis T62 Gauss – 08299 – 0500 LST
6° 40' N 80° 37' E – Elev 115m
01/58–12/97

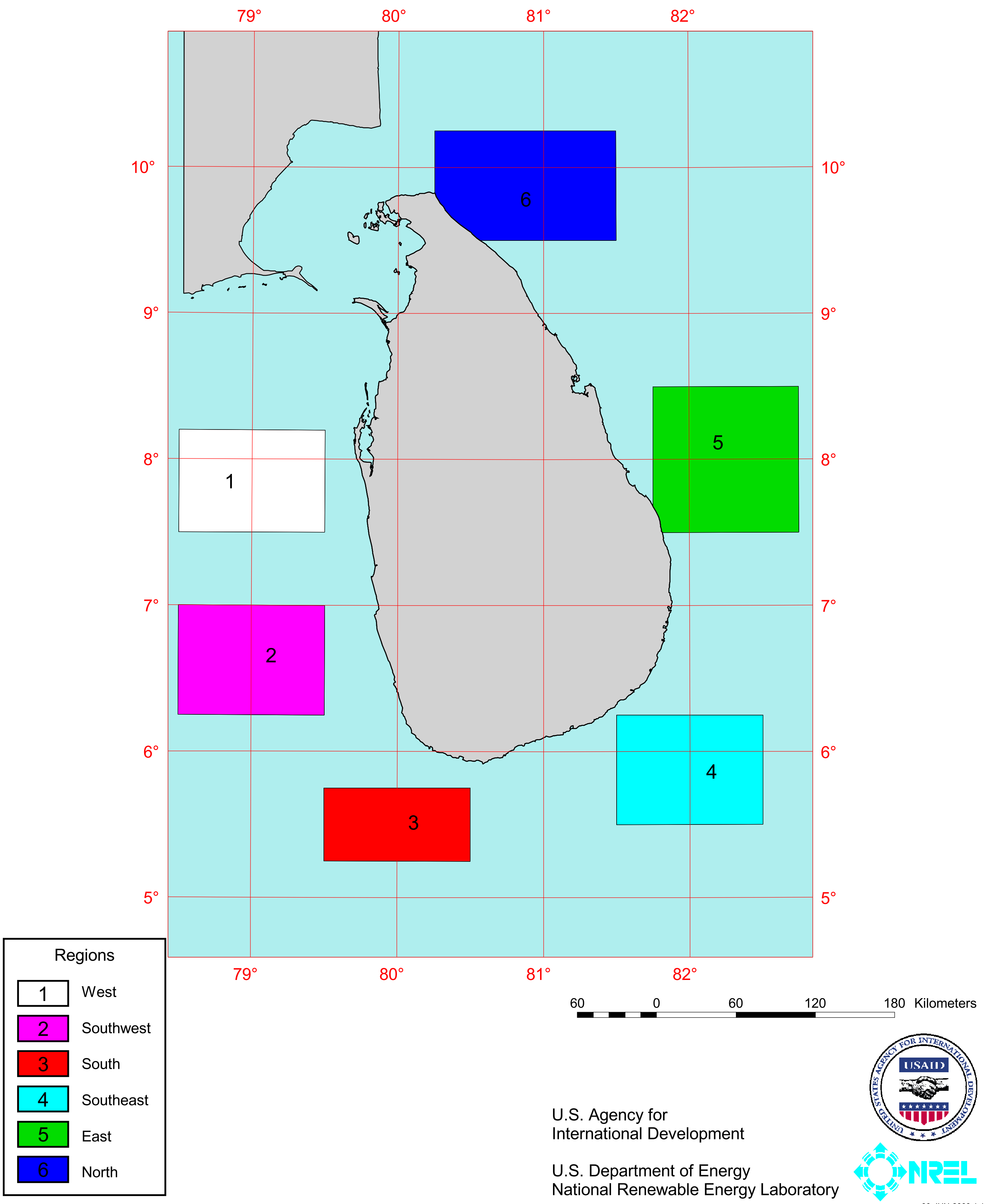


Tue Jun 24 12:33:55 2003

Appendix E:

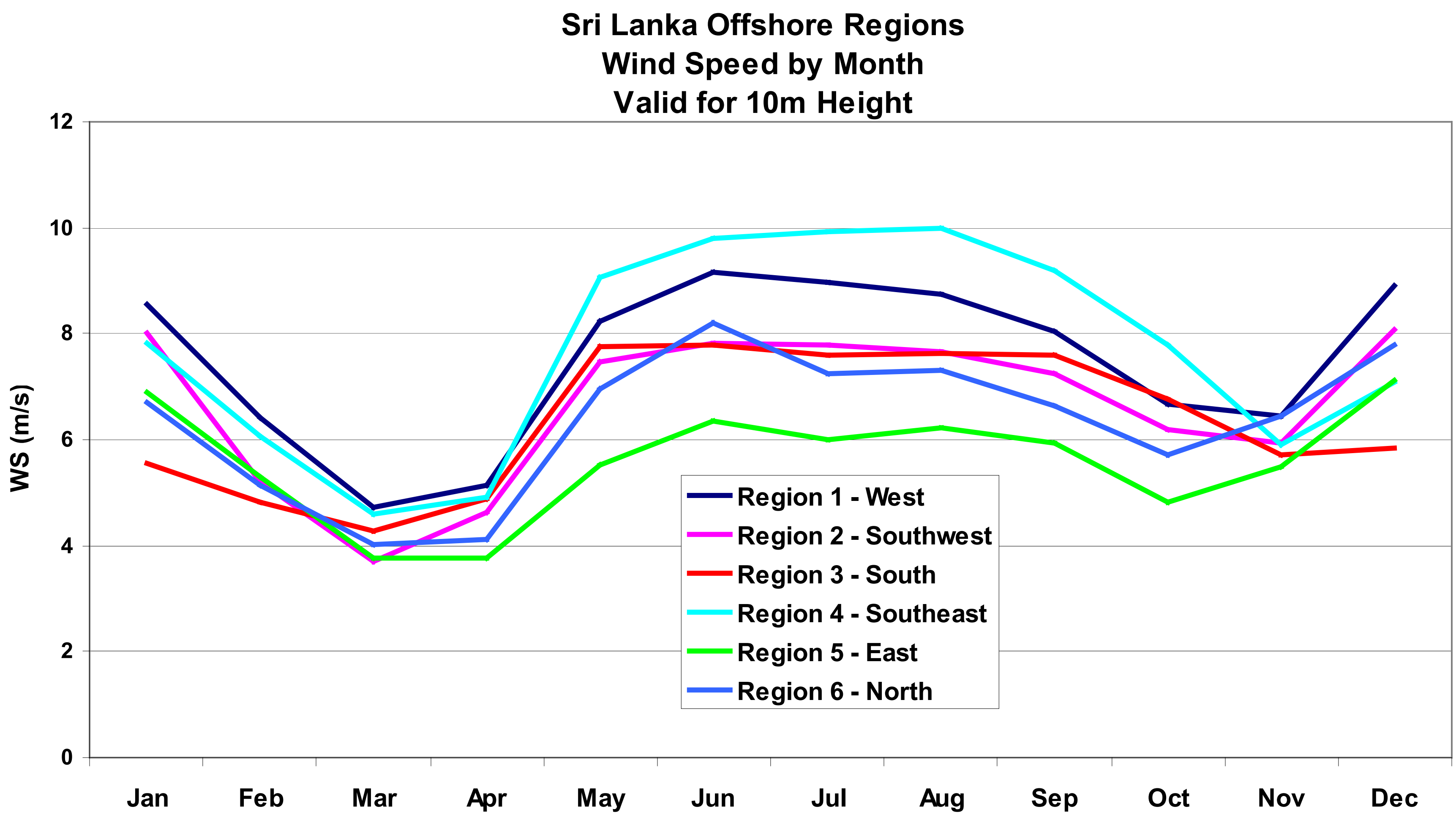
Ocean Satellite Wind Data

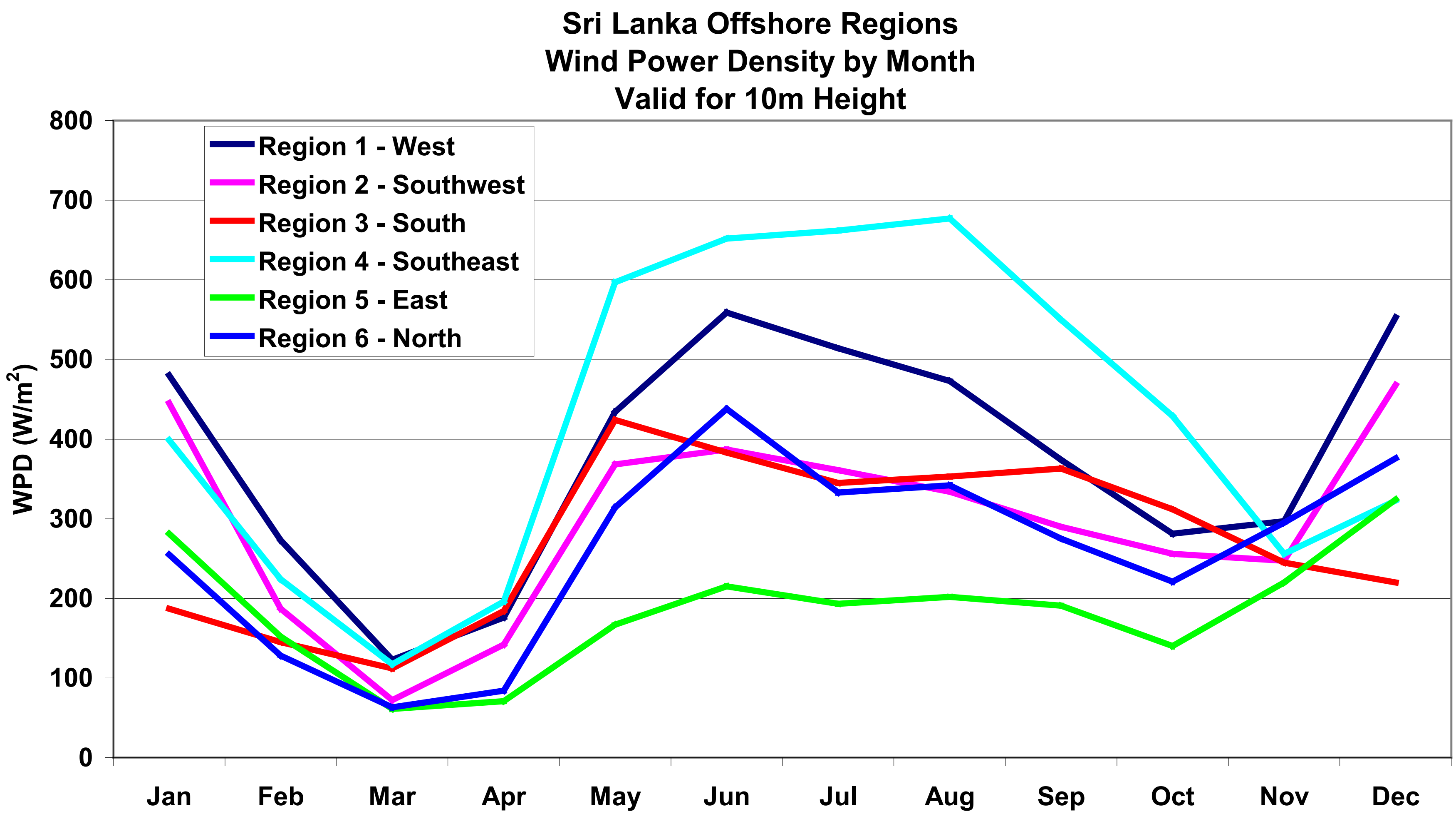
Sri Lanka - Regional Location Map for Satellite Ocean Wind Data

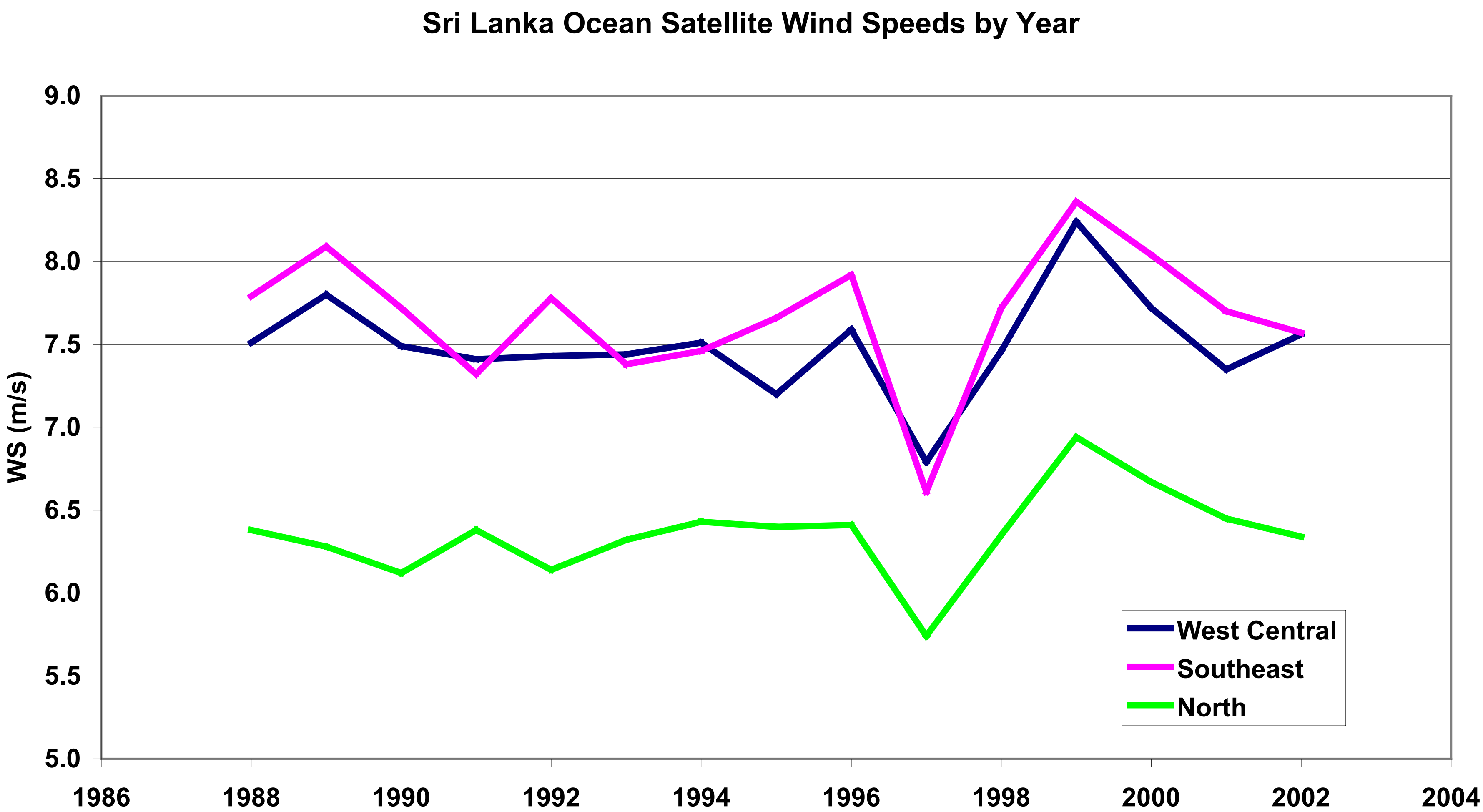


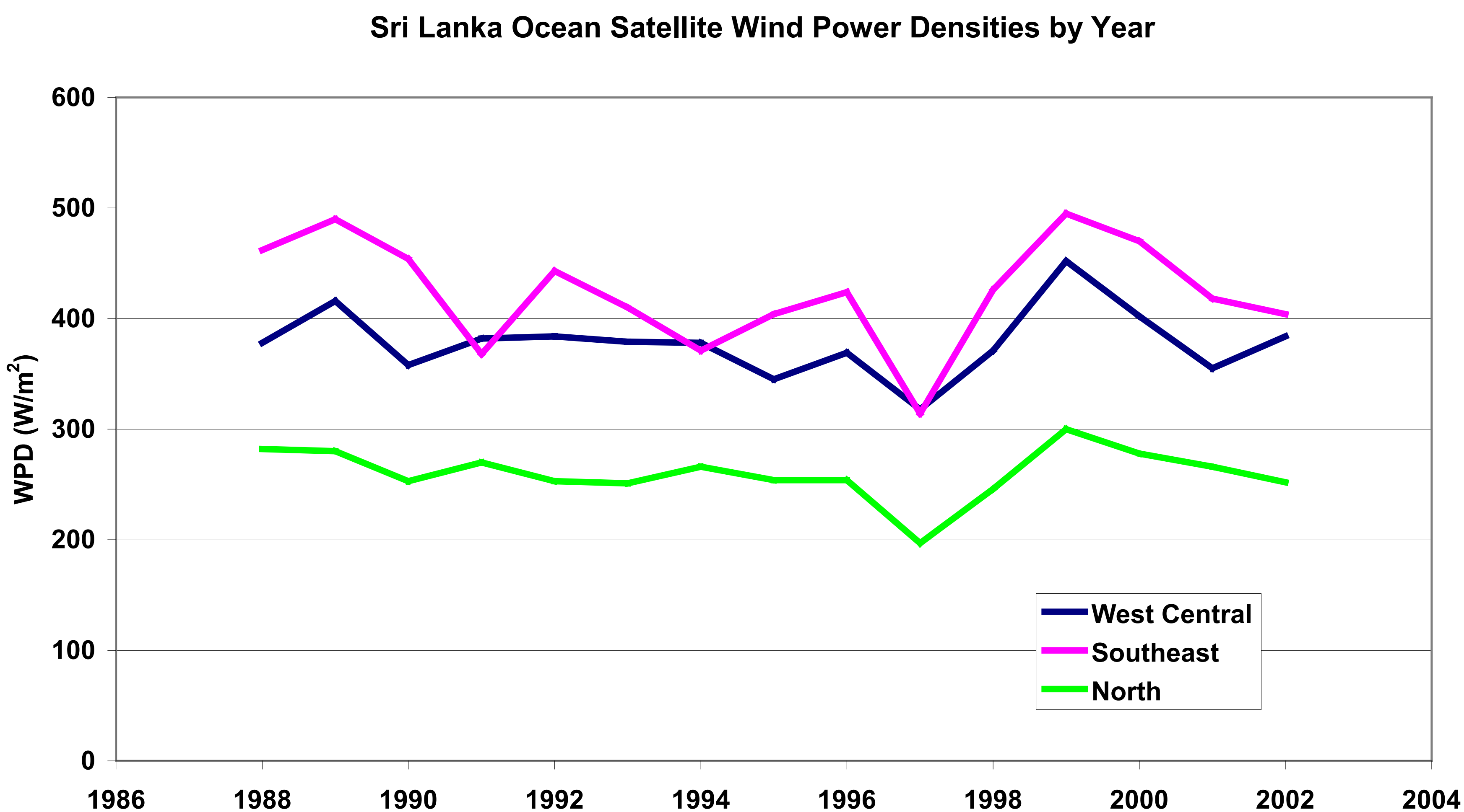
U.S. Agency for
International Development

U.S. Department of Energy
National Renewable Energy Laboratory

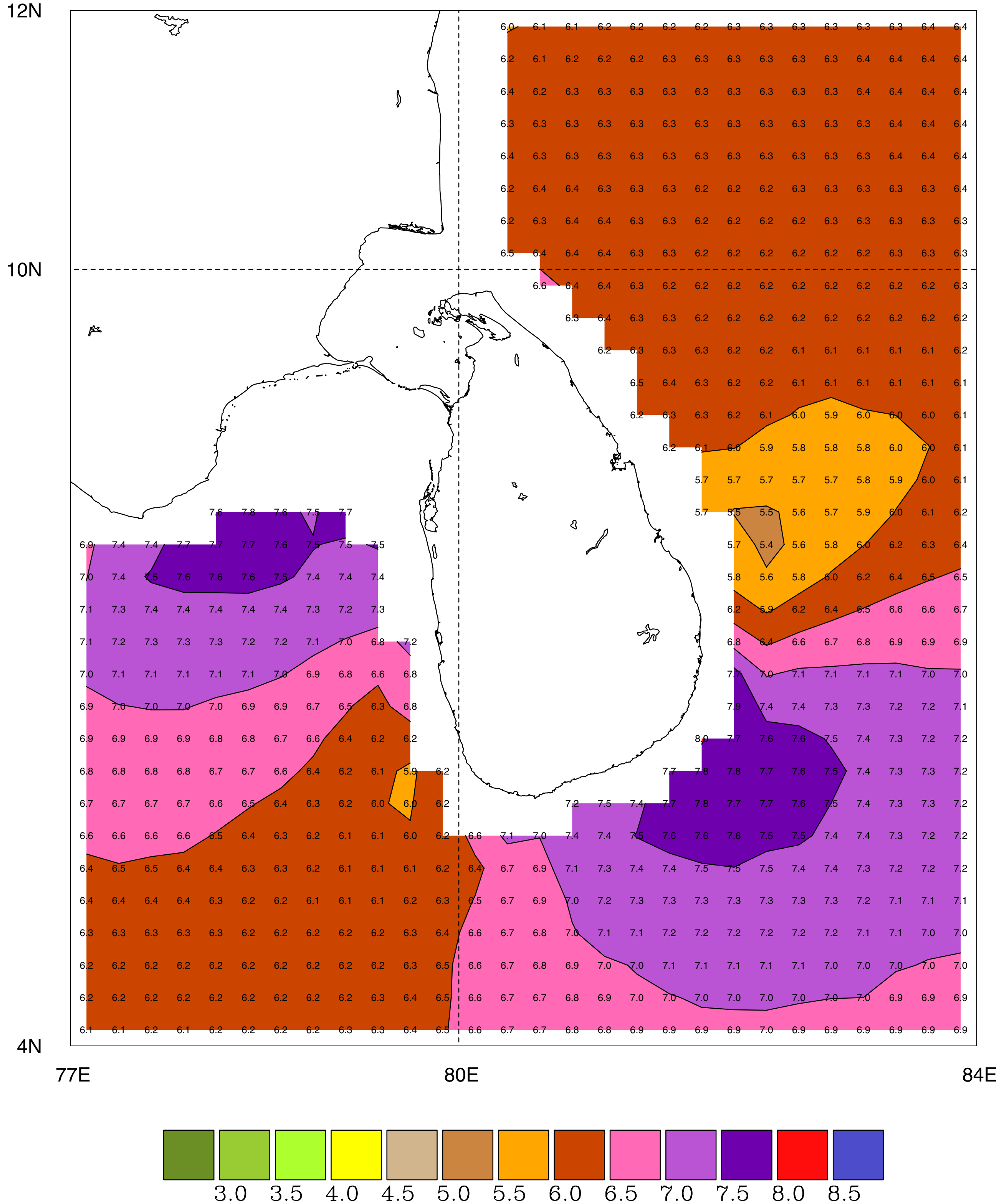

Sri Lanka Offshore Regions
Wind Speed by Month
Valid for 10m Height
WS (m/s)
0
2
4
6
8
10
12
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Region 1 - West
Region 2 - Southwest
Region 3 - South
Region 4 - Southeast
Region 5 - East
Region 6 - North


Sri Lanka Offshore Regions
Wind Power Density by Month
Valid for 10m Height
Region 1 - West
Region 2 - Southwest
Region 3 - South
Region 4 - Southeast
Region 5 - East
Region 6 - North
WPD (W/m2)
0
100
200
300
400
500
600
700
800
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Sri Lanka Ocean Satellite Wind Speeds by Year
WS (m/s)
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
West Central
Southeast
North

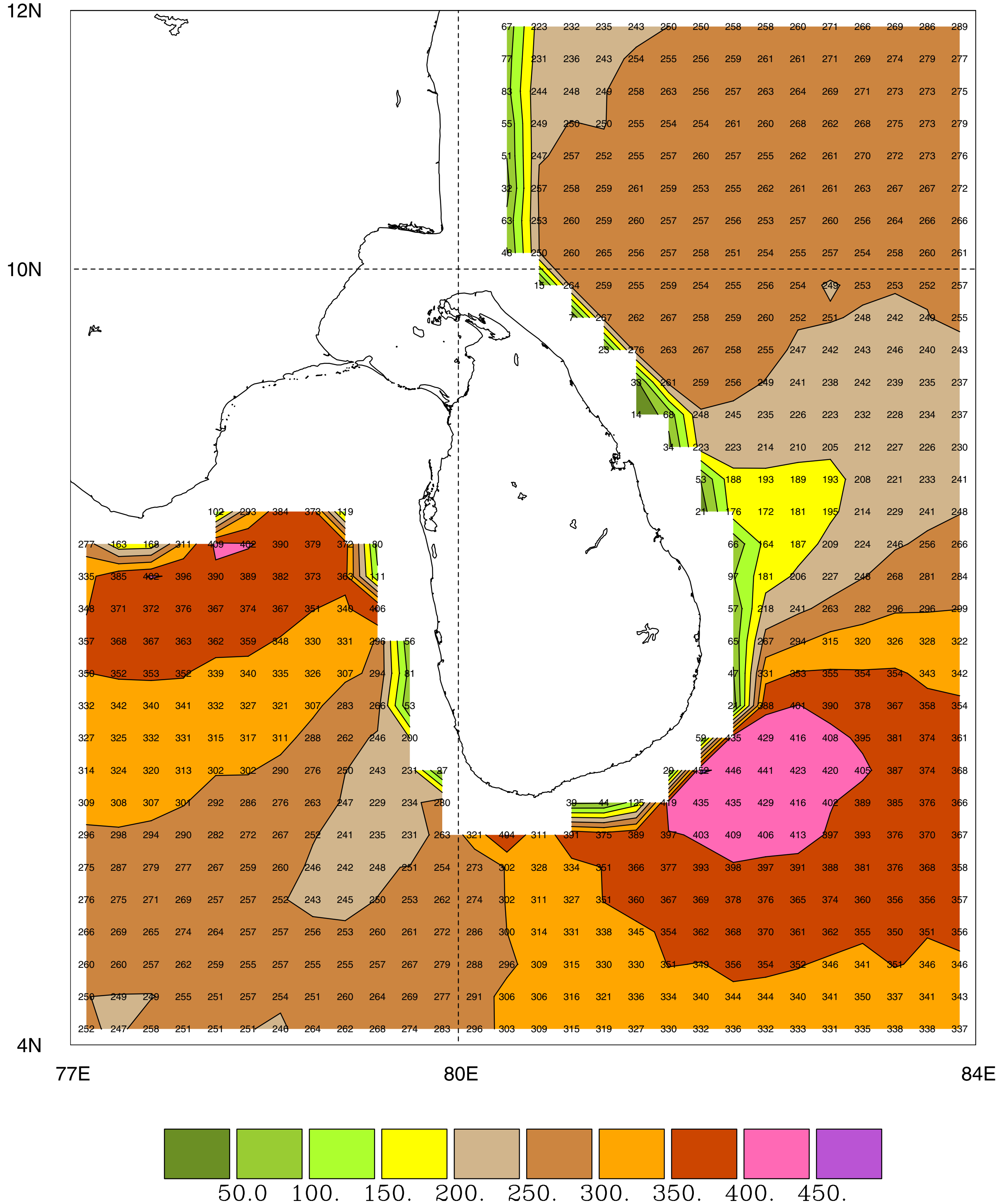

Sri Lanka Ocean Satellite Wind Power Densities by Year
WPD (W/m2)
600
500
400
300
200
100
0
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
West Central
Southeast
North

Wind Speed (m/s) – 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63

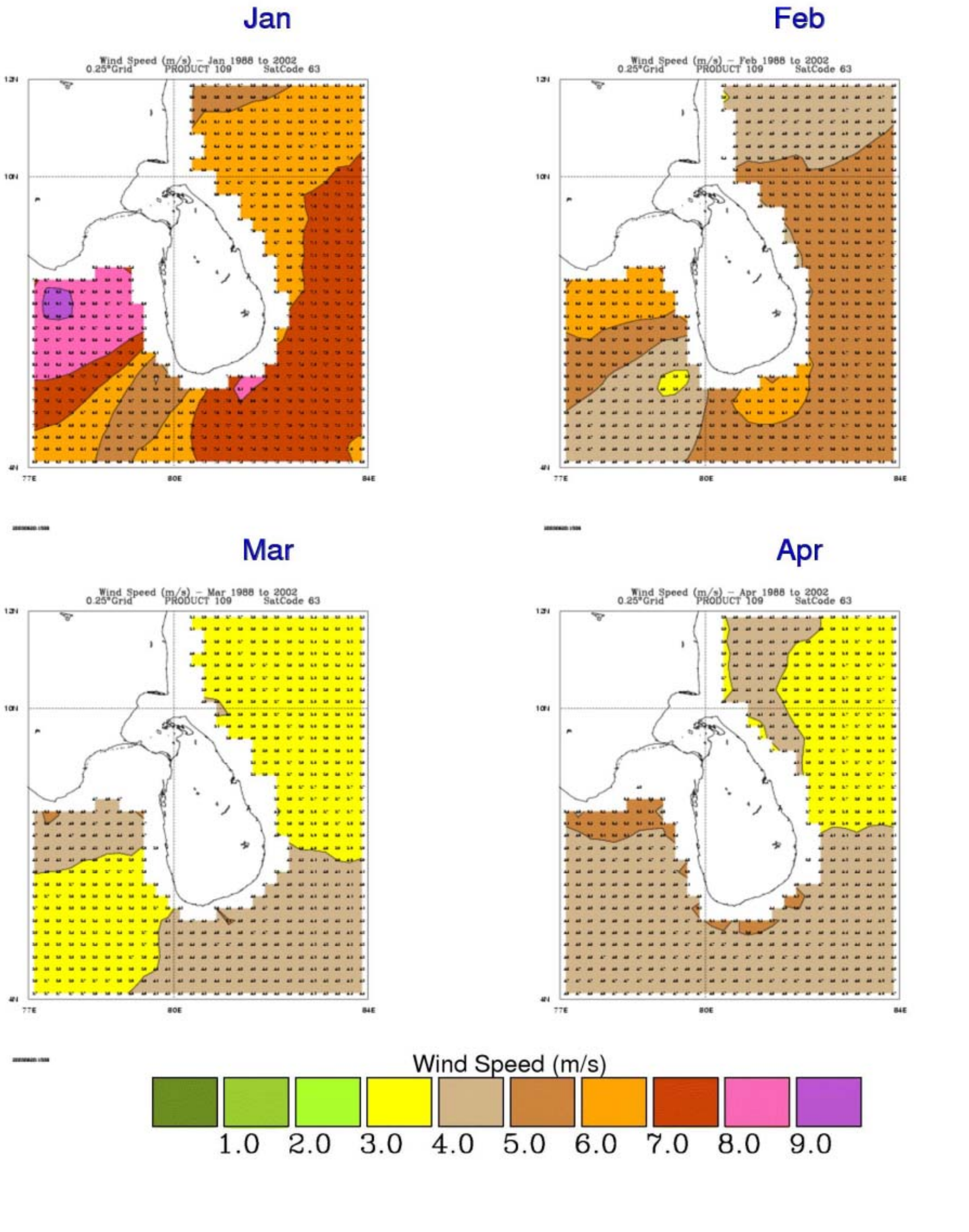


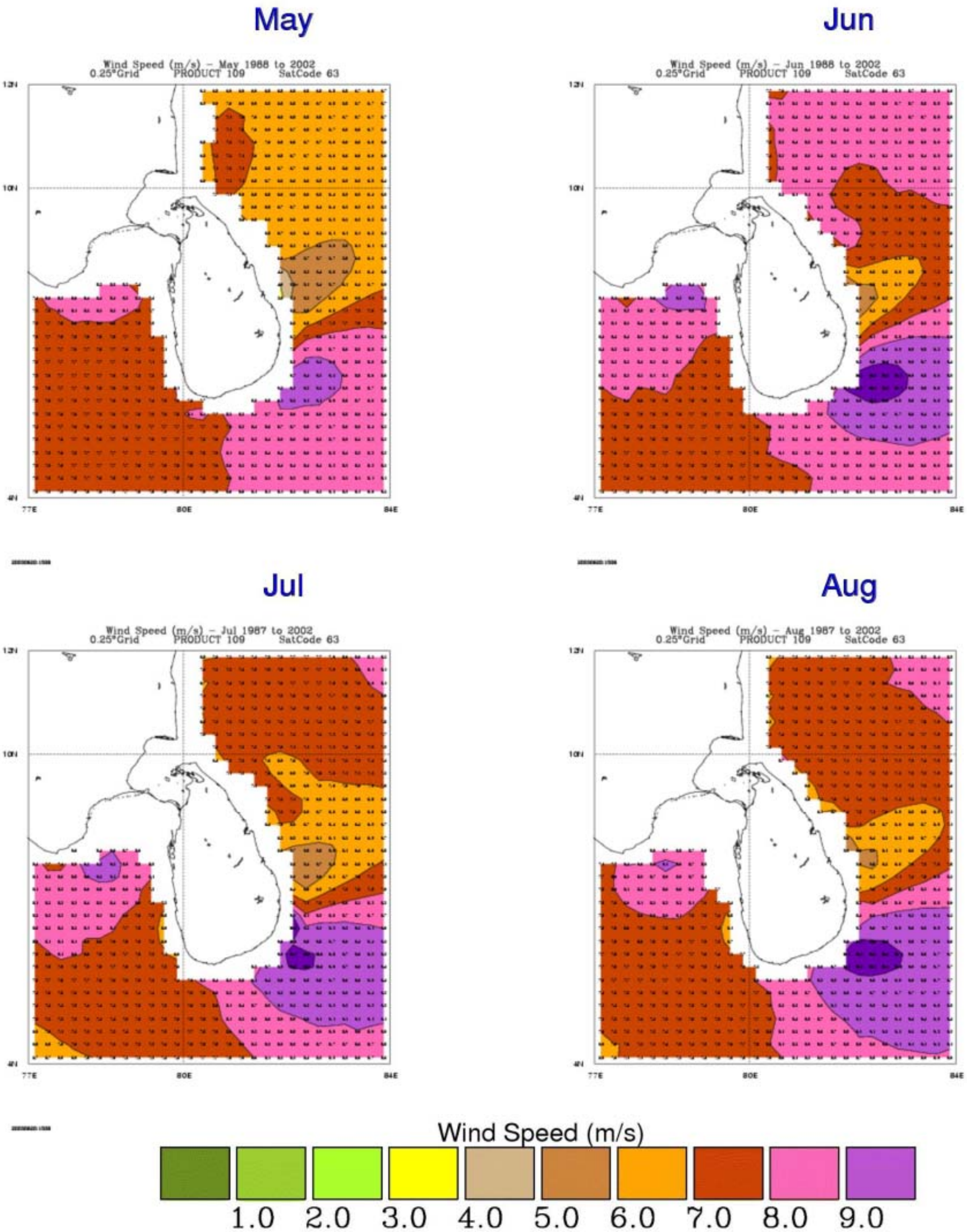
20030630:0903

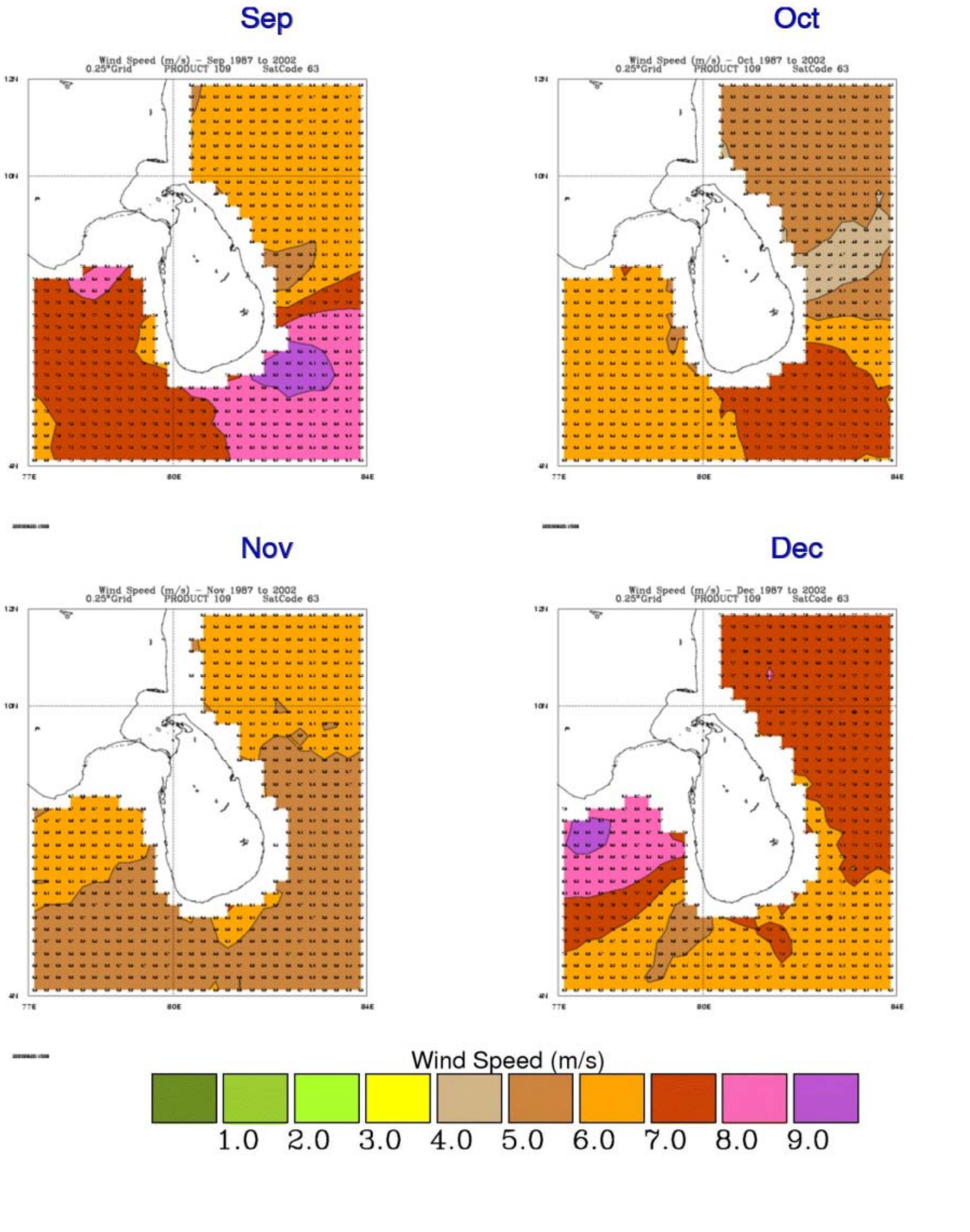
Wind Power Density (W/sq.m) – 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63

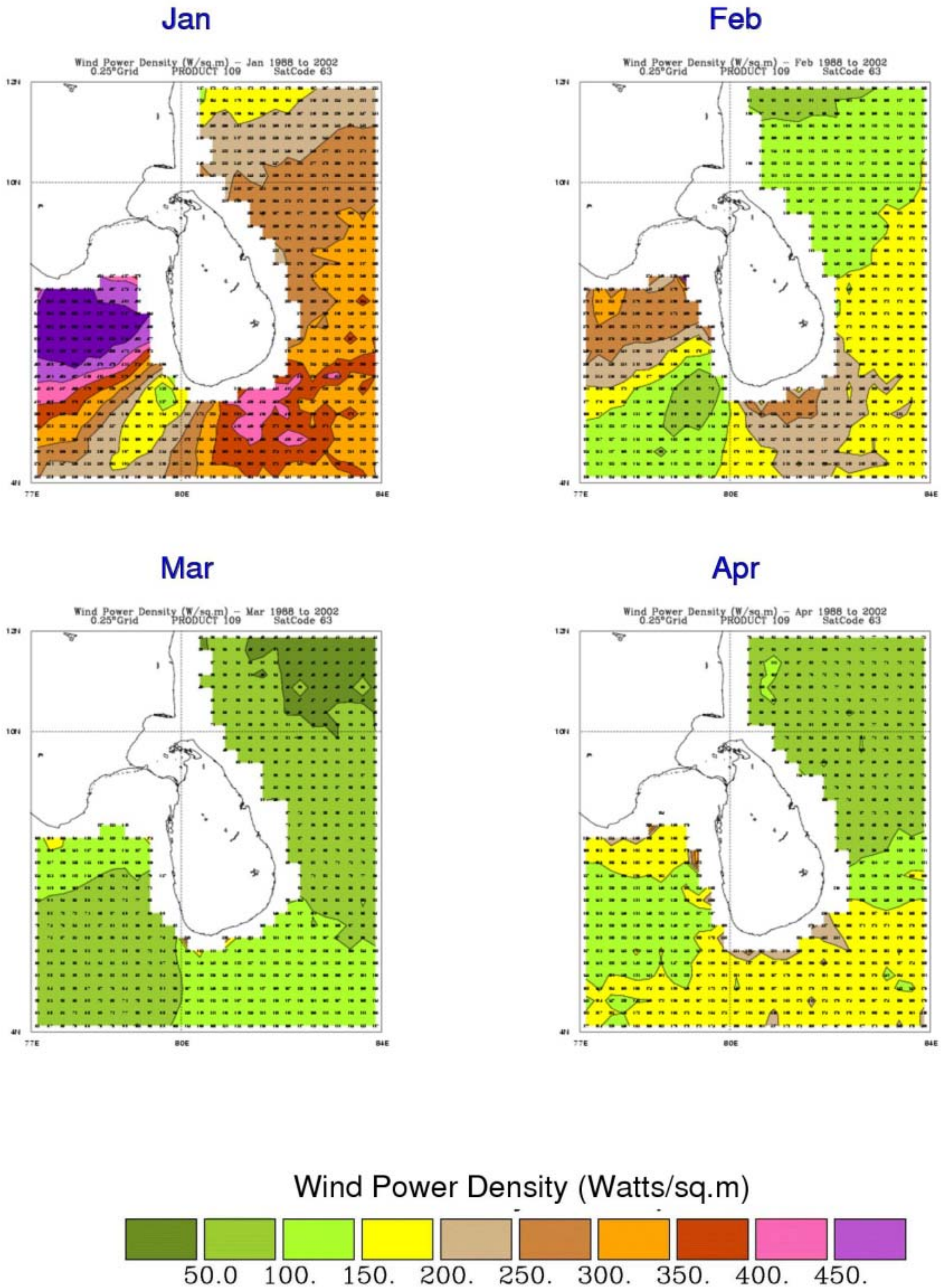


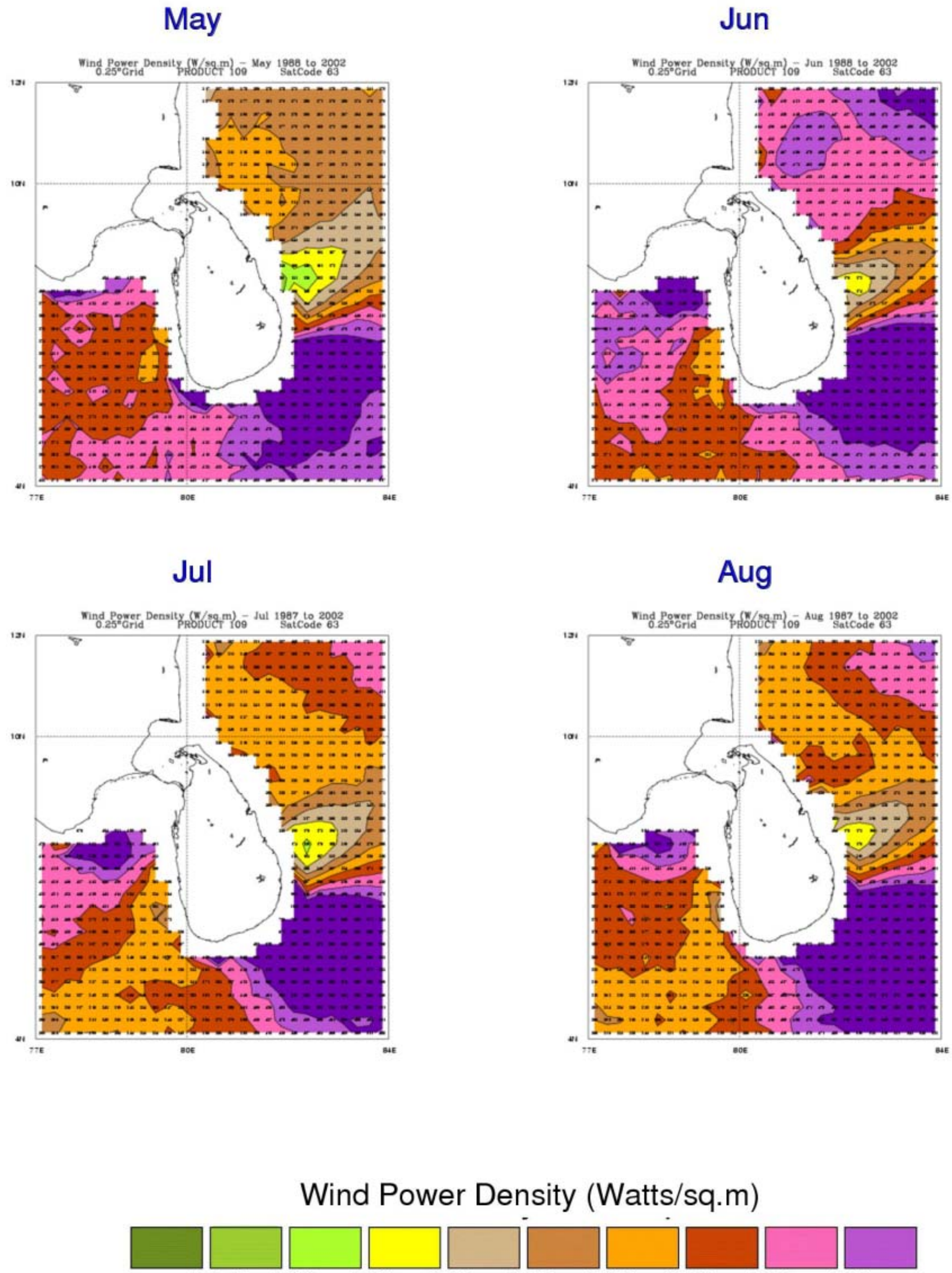
20030630:0905

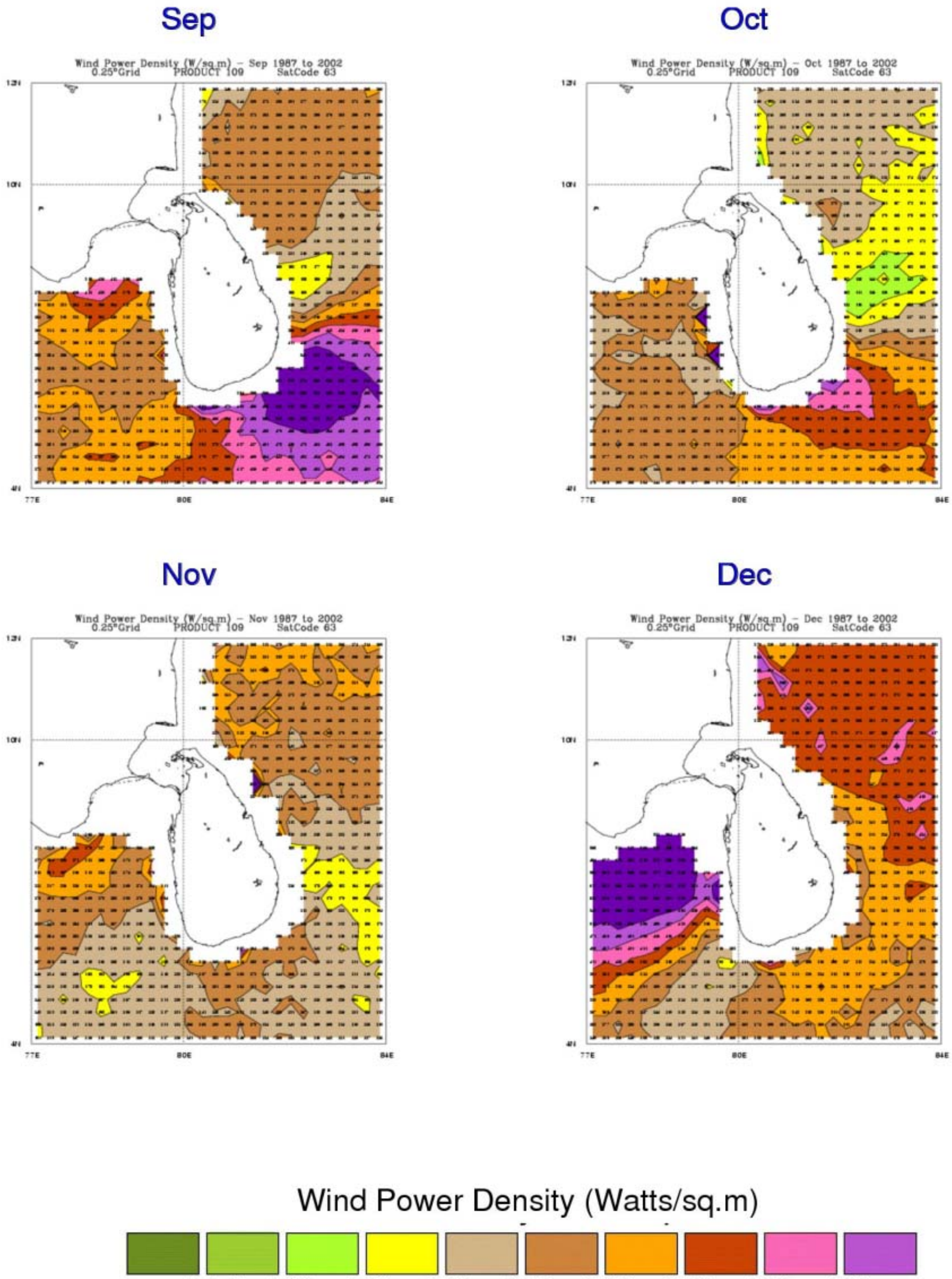

Jan
Wind Speed (m/s) – Jan 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Feb
Wind Speed (m/s) – Feb 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Mar
Wind Speed (m/s) – Mar 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Apr
Wind Speed (m/s) – Apr 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63
12N
10N
4N
77E
80E
84E
Wind Speed (m/s)
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0

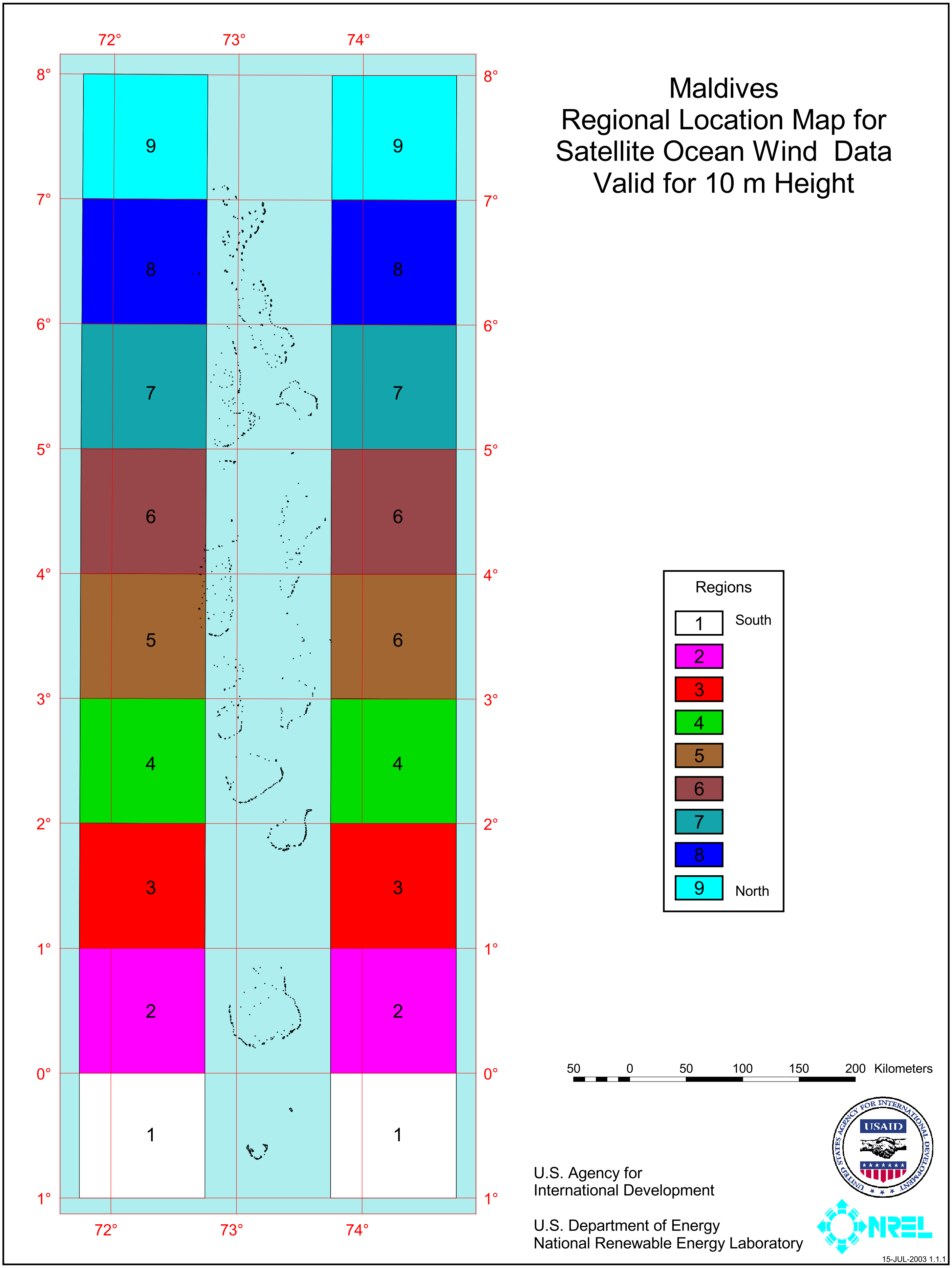

May
Wind Speed (m/s) – May 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Jun
Wind Speed (m/s) – Jun 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Jul
Wind Speed (m/s) – Jul 1987 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Aug
Wind Speed (m/s) – Aug 1987 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Wind Speed (m/s)
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0

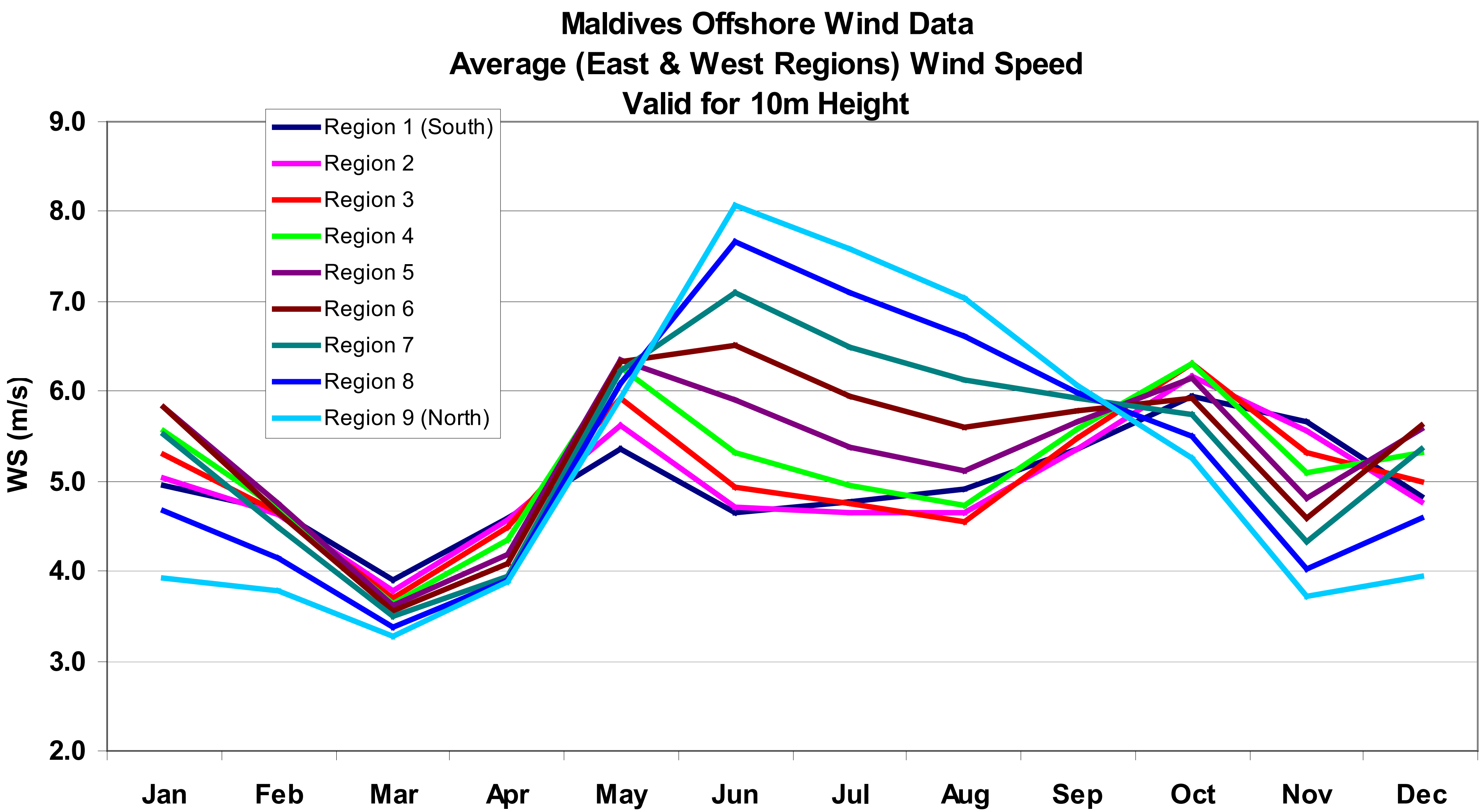

Sep
Wind Speed (m/s) – Sep 1987 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Oct
Wind Speed (m/s) – Oct 1987 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Nov
Wind Speed (m/s) – Nov 1987 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Dec
Wind Speed (m/s) – Dec 1987 to 2002
0.25°Grid PRODUCT 109 SatCode 63
12N
10N
4N
77E
80E
84E
Wind Speed (m/s)
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0

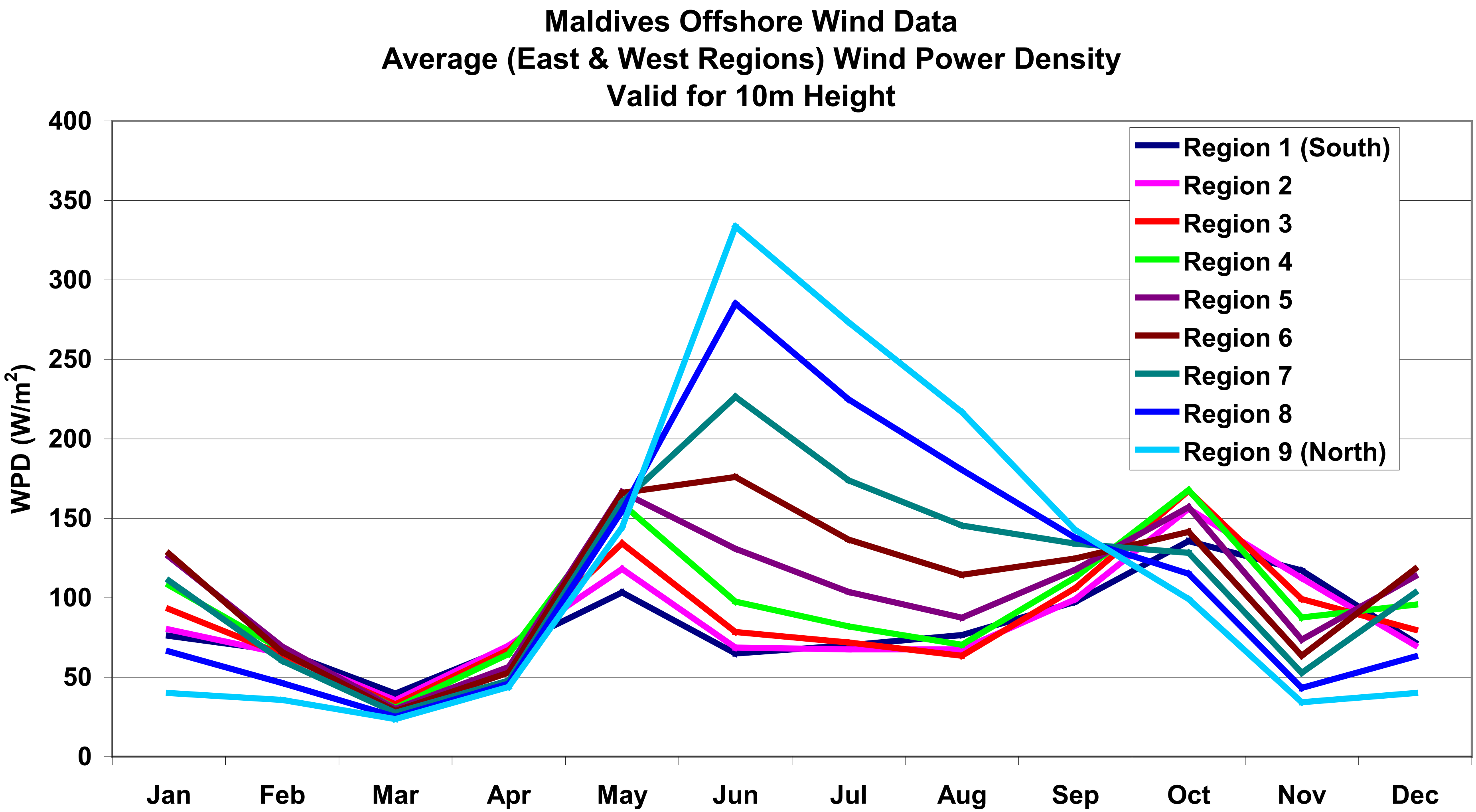

Jan
Wind Power Density (W/sq.m) – Jan 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Feb
Wind Power Density (W/sq.m) – Feb 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Mar
Wind Power Density (W/sq.m) – Mar 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Apr
Wind Power Density (W/sq.m) – Apr 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Wind Power Density (Watts/sq.m)
50.0 100. 150. 200. 250. 300. 350. 400. 450.

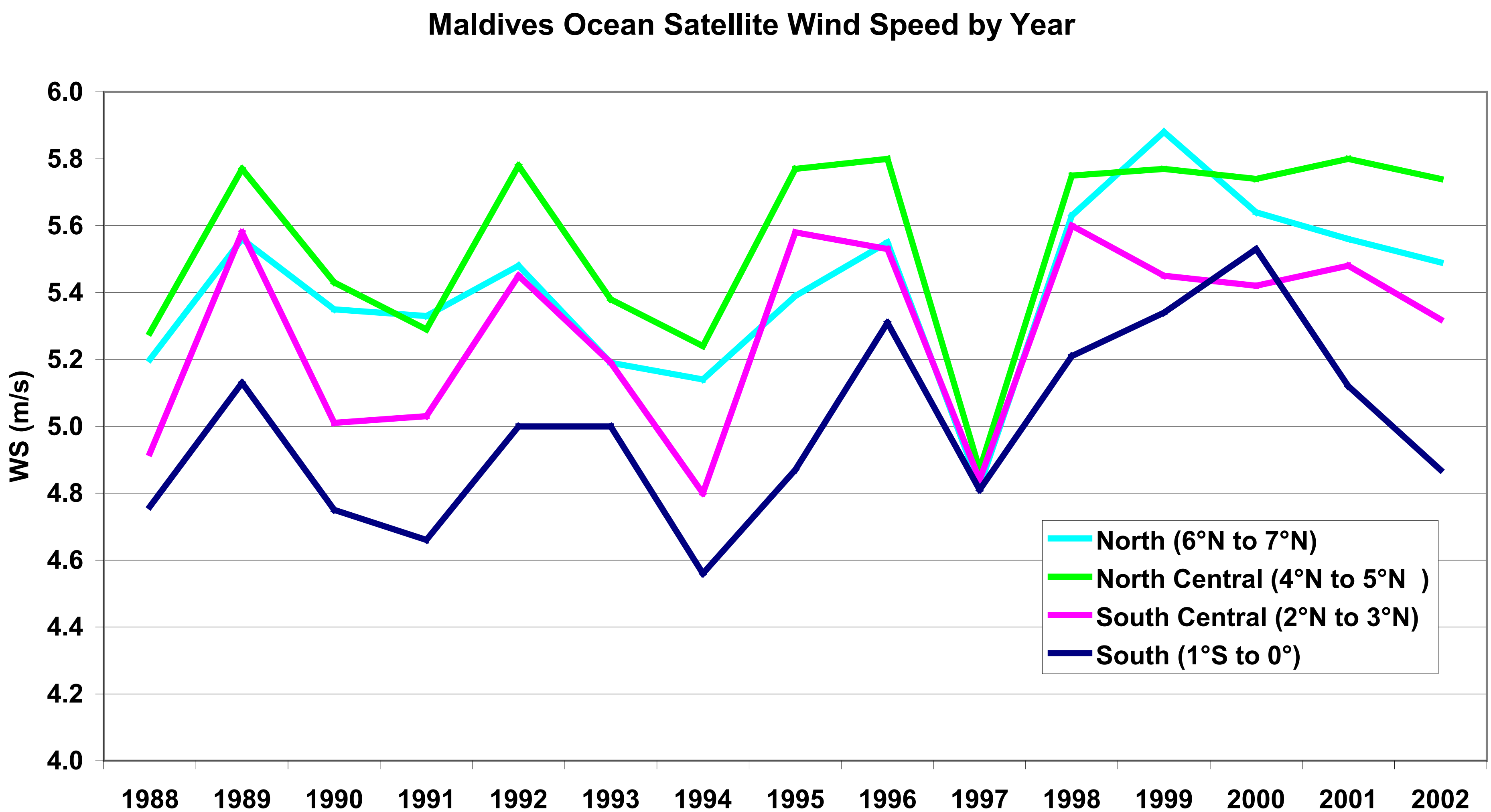

May
Wind Power Density (W/sq.m) – May 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Jun
Wind Power Density (W/sq.m) – Jun 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Jul
Wind Power Density (W/sq.m) – Jul 1987 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Aug
Wind Power Density (W/sq.m) – Aug 1987 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Wind Power Density (Watts/sq.m)
50.0 100. 150. 200. 250. 300. 350. 400. 450.

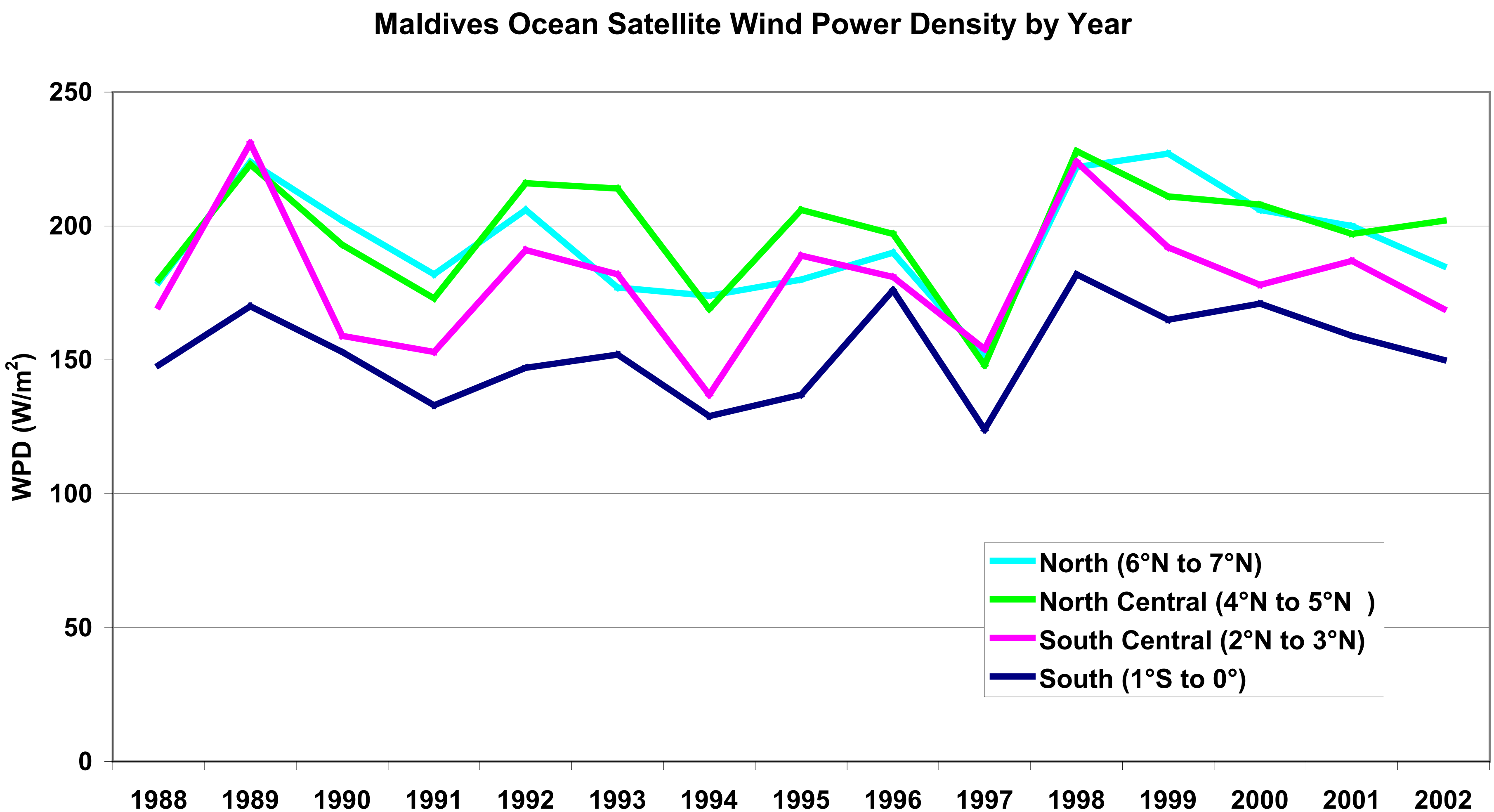

Sep
Wind Power Density (W/sq.m) – Sep 1987 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Oct
Wind Power Density (W/sq.m) – Oct 1987 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Nov
Wind Power Density (W/sq.m) – Nov 1987 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Dec
Wind Power Density (W/sq.m) – Dec 1987 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Wind Power Density (Watts/sq.m)
50.0 100. 150. 200. 250. 300. 350. 400. 450.

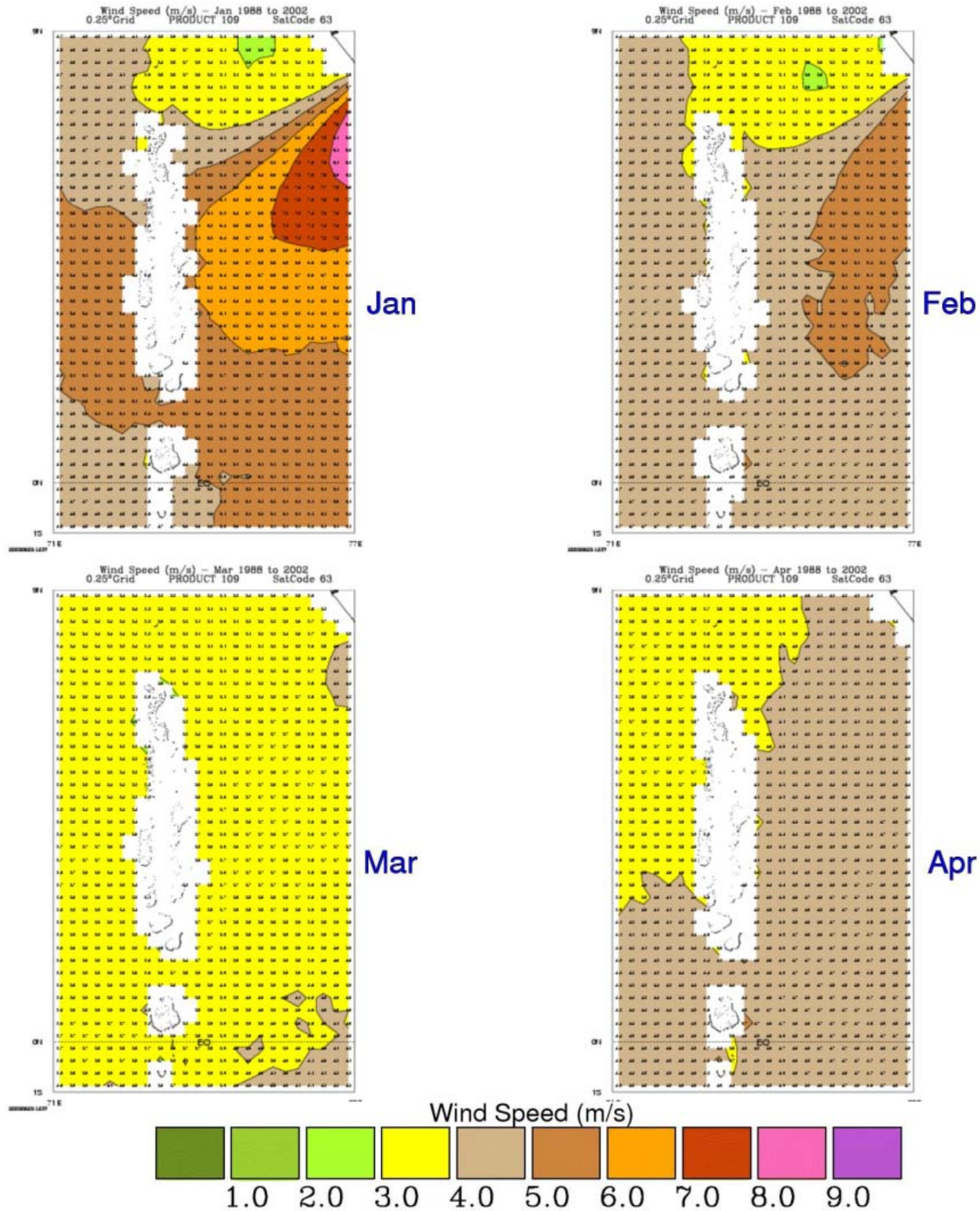

Maldives
Regional Location Map for
Satellite Ocean Wind Data
Valid for 10 m Height
72°
73°
74°
8°
7°
6°
5°
4°
3°
2°
1°
0°
1°
9
8
7
6
5
4
3
2
1
9
8
7
6
6
4
3
2
1
Regions
1 South
2
3
4
5
6
7
8
9 North
50 0 50 100 150 200 Kilometers
U.S. Agency for
International Development
U.S. Department of Energy
National Renewable Energy Laboratory
15-JUL-2003 1.1.1

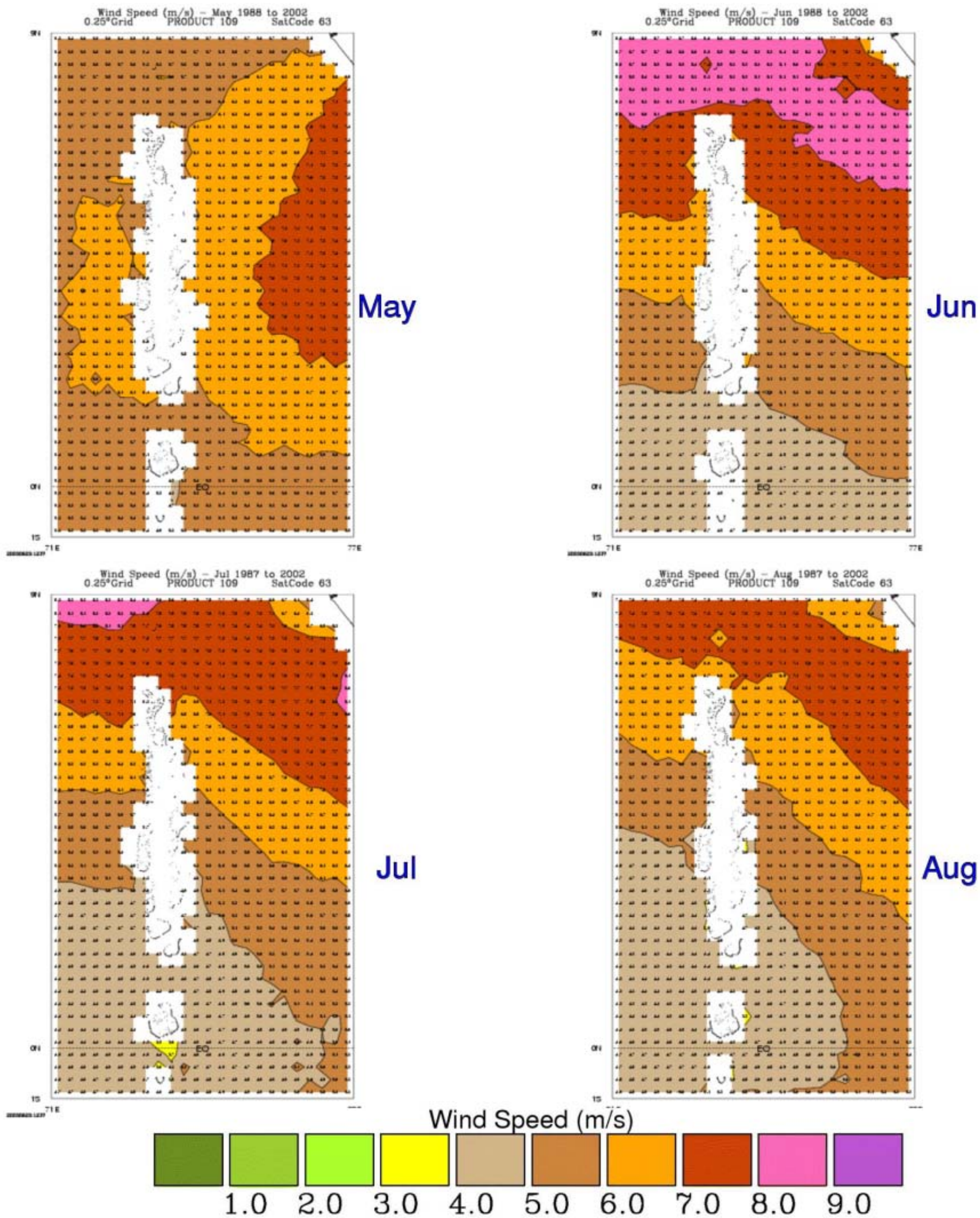

Maldives Offshore Wind Data
Average (East & West Regions) Wind Speed
Valid for 10m Height
Region 1 (South)
Region 2
Region 3
Region 4
Region 5
Region 6
Region 7
Region 8
Region 9 (North)
WS (m/s)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

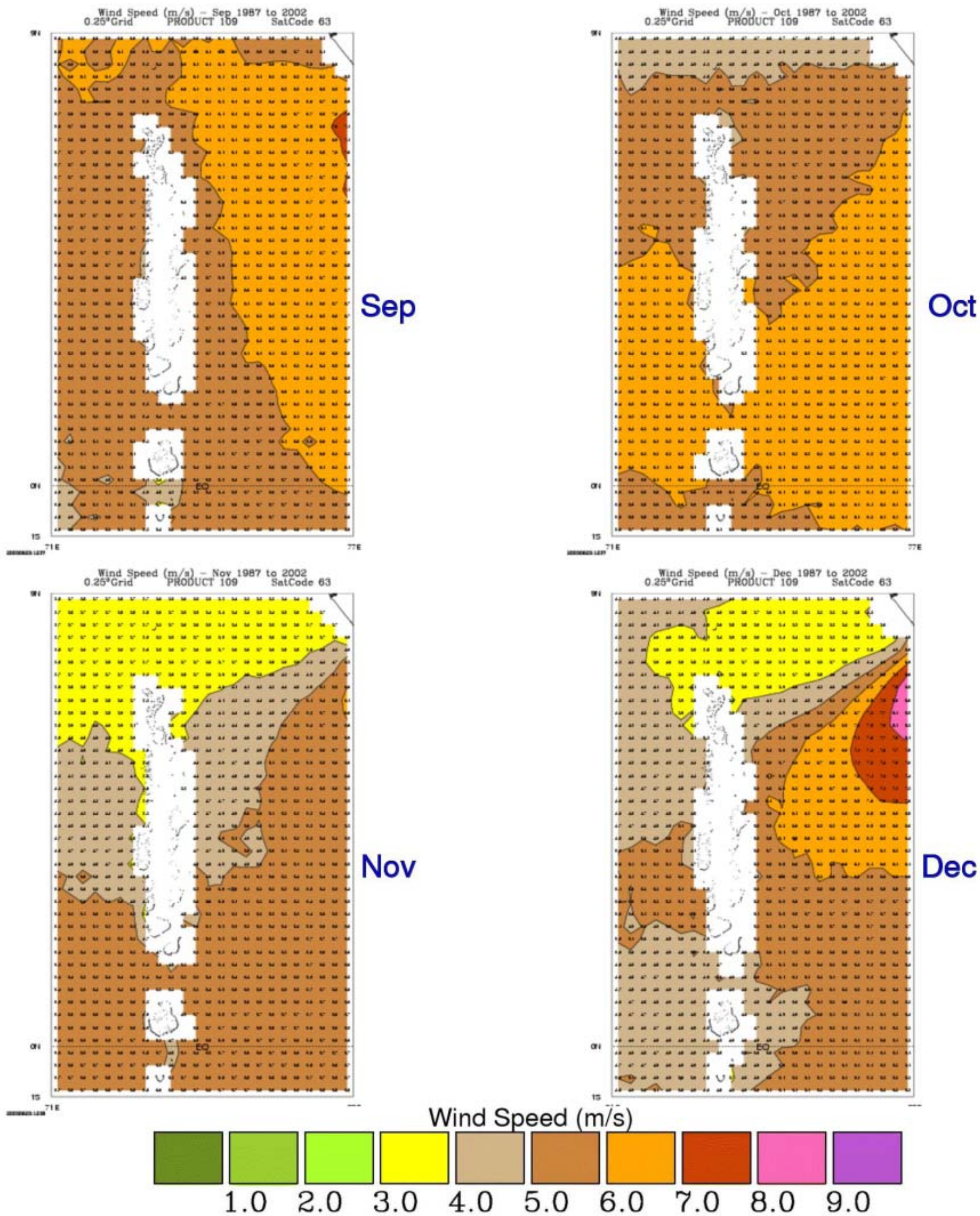

Maldives Offshore Wind Data
Average (East & West Regions) Wind Power Density
Valid for 10m Height
WPD (W/m2)
0
50
100
150
200
250
300
350
400
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Region 1 (South)
Region 2
Region 3
Region 4
Region 5
Region 6
Region 7
Region 8
Region 9 (North)

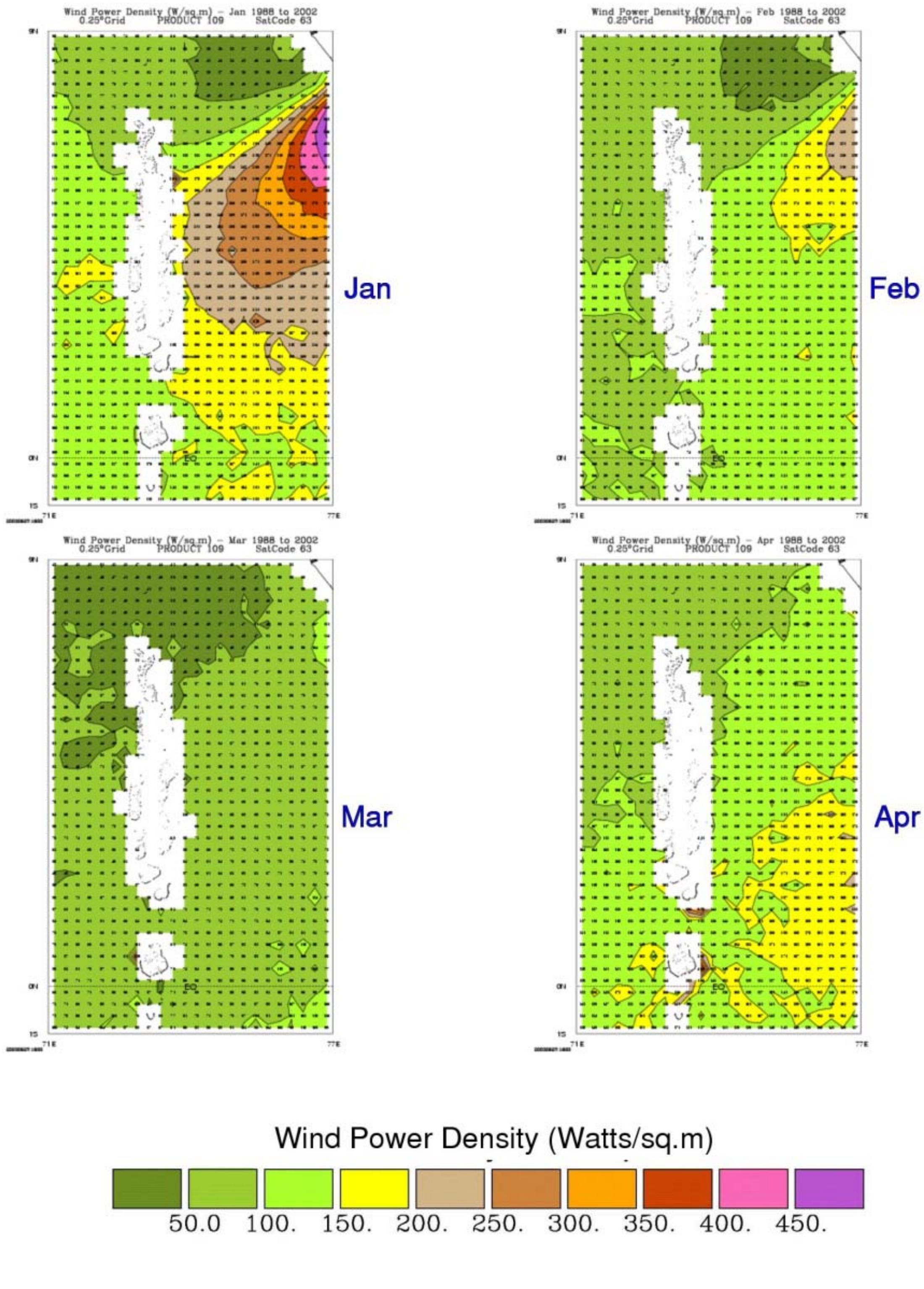

Maldives Ocean Satellite Wind Speed by Year
WS (m/s)
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
4.4
4.2
4.0
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
North (6°N to 7°N)
North Central (4°N to 5°N)
South Central (2°N to 3°N)
South (1°S to 0°)

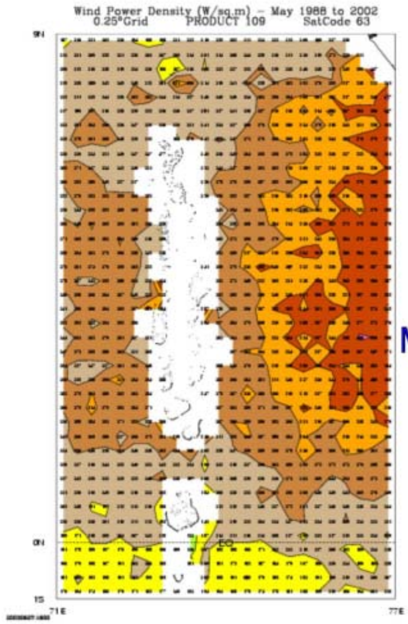

Maldives Ocean Satellite Wind Power Density by Year
WPD (W/m2)
250
200
150
100
50
0
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
North (6°N to 7°N)
North Central (4°N to 5°N)
South Central (2°N to 3°N)
South (1°S to 0°)


Wind Speed (m/s) – Jan 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Jan
Wind Speed (m/s) – Feb 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Feb
Wind Speed (m/s) – Mar 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Mar
Wind Speed (m/s) – Apr 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Apr
Wind Speed (m/s)
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0

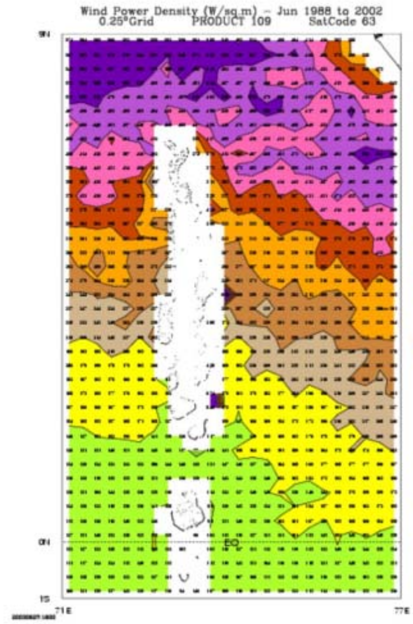

Wind Speed (m/s) – May 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63
May
Wind Speed (m/s) – Jun 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Jun
Wind Speed (m/s) – Jul 1987 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Jul
Wind Speed (m/s) – Aug 1987 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Aug
EQ
Wind Speed (m/s)
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0


Wind Speed (m/s) – Sep 1987 to 2002
0.25°Grid PRODUCT 109 SatCode 63
EQ
Sep
Wind Speed (m/s) – Oct 1987 to 2002
0.25°Grid PRODUCT 109 SatCode 63
EQ
Oct
Wind Speed (m/s) – Nov 1987 to 2002
0.25°Grid PRODUCT 109 SatCode 63
EQ
Nov
Wind Speed (m/s) – Dec 1987 to 2002
0.25°Grid PRODUCT 109 SatCode 63
EQ
Dec
Wind Speed (m/s)
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0


Wind Power Density (W/sq.m) – Jan 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Jan
Wind Power Density (W/sq.m) – Feb 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Feb
Wind Power Density (W/sq.m) – Mar 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Mar
Wind Power Density (W/sq.m) – Apr 1988 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Apr
Wind Power Density (Watts/sq.m)
50.0 100. 150. 200. 250. 300. 350. 400. 450.



May



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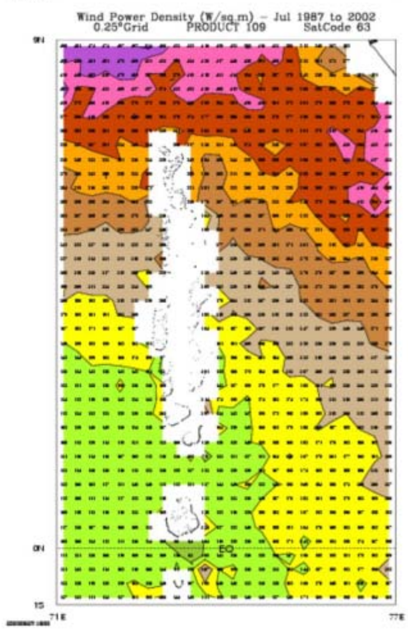
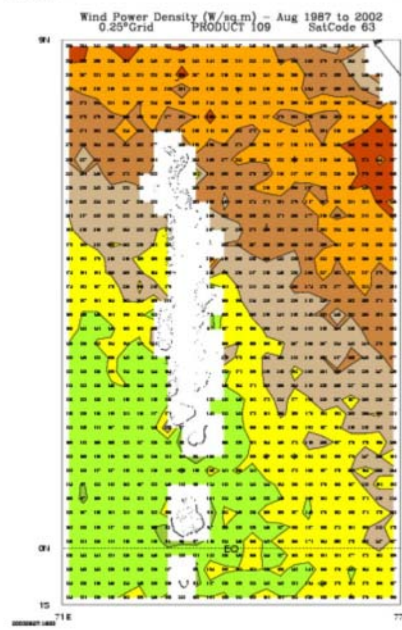


Jul



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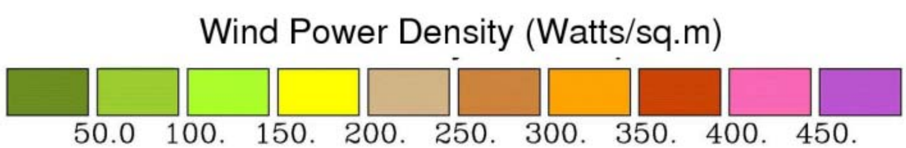

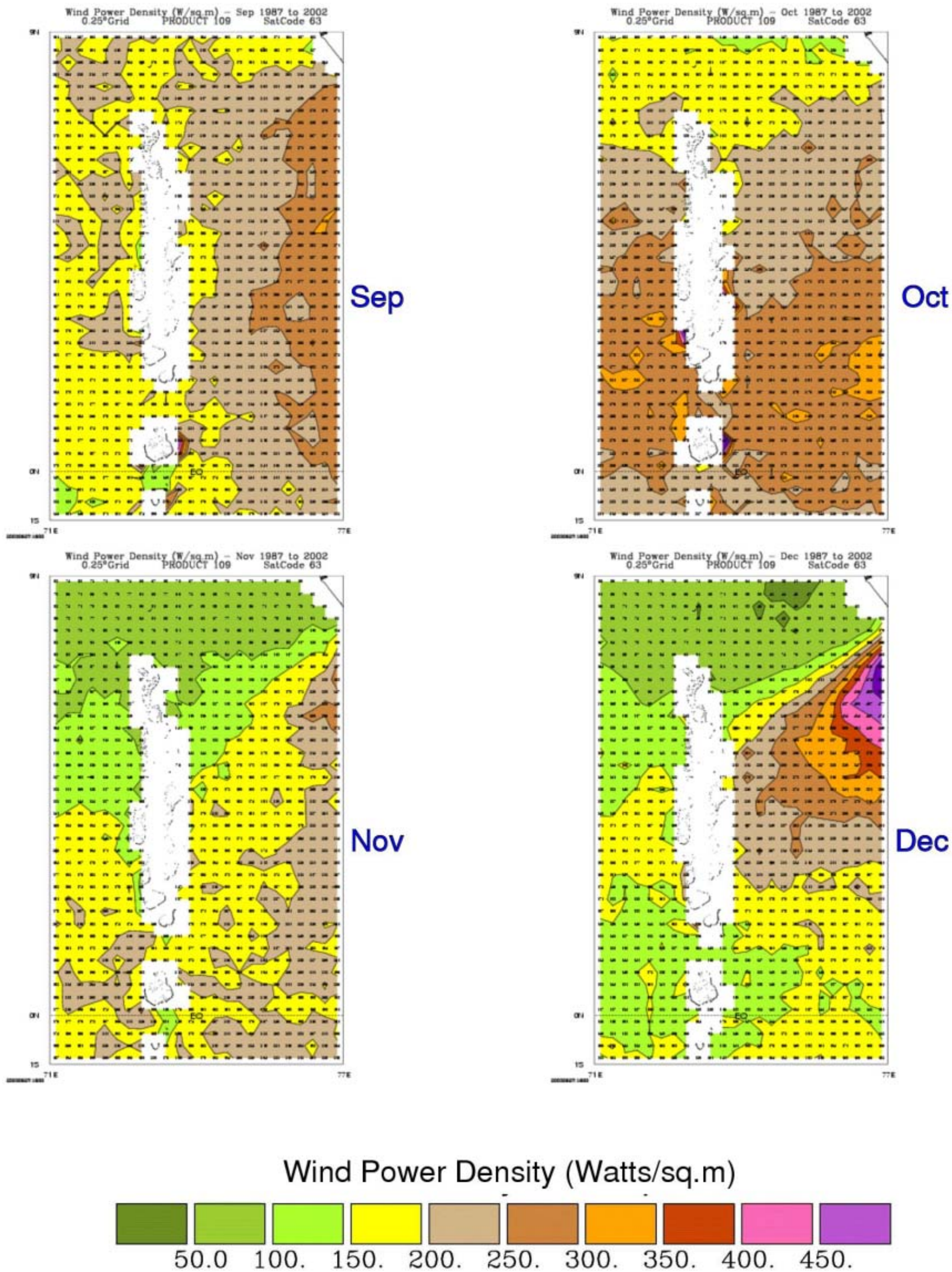
Wind Power Density (W/sq.m) - Sep 1987 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Sep
Wind Power Density (W/sq.m) - Oct 1987 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Oct
Wind Power Density (W/sq.m) - Nov 1987 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Nov
Wind Power Density (W/sq.m) - Dec 1987 to 2002
0.25°Grid PRODUCT 109 SatCode 63
Dec
Wind Power Density (Watts/sq.m)
50.0 100. 150. 200. 250. 300. 350. 400. 450.

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The Wind Energy Resource Atlas of Sri Lanka and the Maldives, produced by the National Renewable Energy Laboratory's (NREL's) wind resource group identifies the wind characteristics and distribution of the wind resource in Sri Lanka and the Maldives. The detailed wind resource maps and other information contained in the atlas facilitate the identification of prospective areas for use of wind energy technologies, both for utility-scale power generation and off-grid wind energy applications.

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